

# COMBUSTION

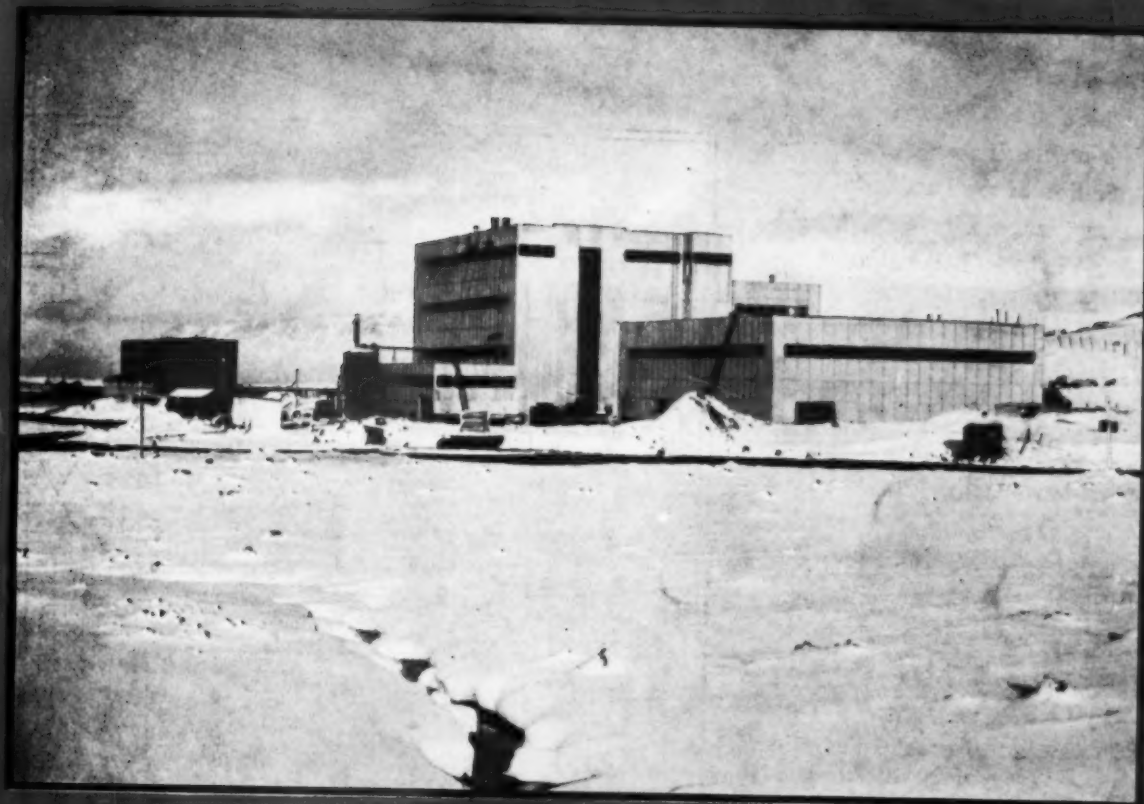
DEVOTED TO THE ADVANCEMENT OF STEAM PLANT DESIGN AND OPERATION

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**August, 1948**

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See page 22

**Factors Governing  
Selection of Feedwater Treatment ▶**

**Appraisal of the Coal Industry ▶**

**New Steam Cycle Proposal ▶**

# Recent C-E Steam Generating Units for Utilities

## ALEXANDRIA STATION

**BRADDOCK LIGHT & POWER COMPANY, INC.**

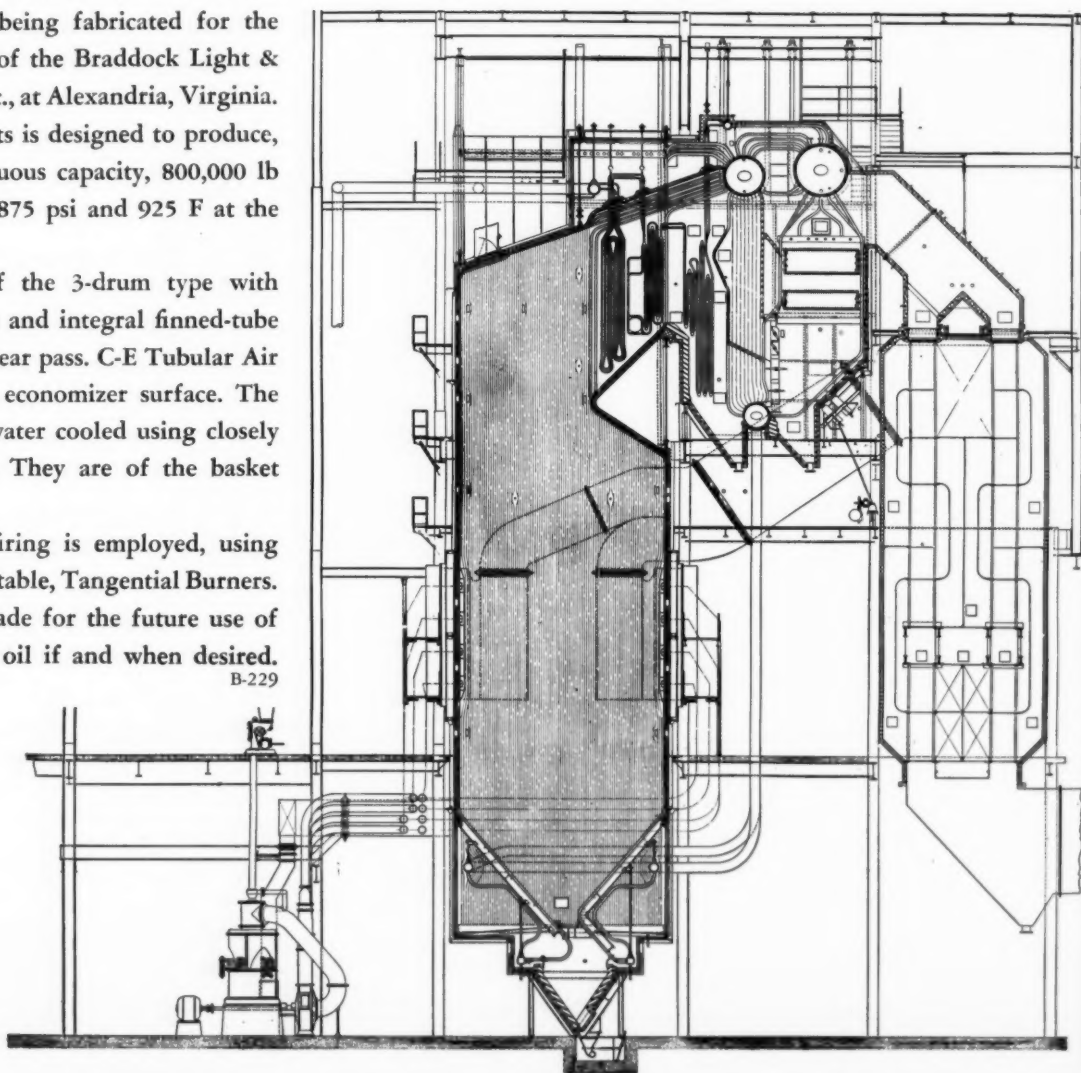
**T**HE C-E Unit illustrated here is one of two such units now being fabricated for the Alexandria Station of the Braddock Light & Power Company, Inc., at Alexandria, Virginia.

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# COMBUSTION

DEVOTED TO THE ADVANCEMENT OF STEAM PLANT DESIGN AND OPERATION

VOLUME TWENTY

NUMBER TWO

## CONTENTS

FOR AUGUST 1948

### FEATURE ARTICLES

- Economic Factors Governing the Selection of Feedwater Treatment.....by *Frank N. Kemmer* 30  
Appraisal of the Coal Industry.....by *J. E. Tobey* 35  
The "New Look" in Power Stations.....38 & 39  
New Steam Cycle Proposed.....by *J. F. Field* 40  
Internal Treatment with Magnesium Chloride in Absence of Phosphate...by *F. H. Long and W. A. Pollock* 47

### EDITORIALS

- Conflicting Restrictions.....29  
Student Guidance to Receive Greater Attention.....29  
Conference to Feature Instrumentation.....29

- Advertisers in This Issue.....52

GERALD S. CARRICK,  
*General Representative*

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*Editor*

THOMAS E. HANLEY,  
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Published monthly by COMBUSTION PUBLISHING COMPANY, INC., 200 Madison Ave., New York 16  
A SUBSIDIARY OF COMBUSTION ENGINEERING COMPANY, INC.

Frederic A. Schaff, President; Charles McDonough, Vice-President; H. H. Berry, Secretary and Treasurer.

COMBUSTION is sent gratis to engineers in the U. S. A. in charge of steam plants from 500 rated boiler horsepower up and to consulting engineers in this field. To others the subscription rate, including postage, is \$3 in the United States, \$3.50 in Canada and Latin America and \$4 in other countries. Single copies: 30 cents. Copyright 1948 by Combustion Publishing Company, Inc. Issued the middle of the month of publication.

Publication office, 200 Madison Ave., New York  Member of the Controlled Circulation Audit, Inc.

Printed in U. S. A.

# Economic Factors

## Governing the Selection of Feedwater Treatment

By FRANK N. KEMMER

Cochrane Corporation, Philadelphia, Pa.

Although new processes and reagents are being made available for conditioning boiler makeup, they should be examined carefully by cost comparison with the more conventional treatments available for reduction of hardness, alkalinity, total solids and silica. Data here presented indicate the economies of reagents available for such reduction. Costs are presented on an equivalent basis to provide a relative index. Lime or dolomitic lime is applicable to each of the reduction processes at low cost. The limited efficiency of ion exchange systems is emphasized by the index. Consideration is also given to other factors modifying equipment selection.

THE important considerations in the selection of a feedwater conditioning system concern the reduction of hardness, alkalinity, total solids and silica.

Not so long ago sludge was accepted as a constituent of boiler water, and absence of sludge was considered an indication that hardness in the feedwater was forming scale. In the case of low-pressure boilers, particularly where the boiler tubes are large, sludge due to residual hardness in the feedwater is still permissible and the added cost for obtaining low residual hardness is seldom justified. However, the effect of sludge on circulation rates and the influence of suspended solids in inducing carryover make it desirable to keep high-pressure boilers free of sludge, especially for operation at pressures over 1200 psi. "Zero by the soap test" is no longer good enough for high-pressure boiler feed; for such service the feedwater hardness should not exceed 1 to 2 ppm by gravimetric analysis.

In the controversy of alkalinity versus carryover and embrittlement it seems generally conceded that in equal concentrations alkaline salts have a greater tendency to induce carryover than do other solids, which is sufficient information to demand caution where highly alkaline supplies prevail. Regarding the effect of bicarbonate and carbonate salts on liberation of carbon dioxide with steam, however, there can be no dispute. At least 80 per cent of the carbonate alkalinity in a feedwater is converted to caustic soda in the boiler with a corresponding

liberation of carbon dioxide with the steam. Therefore, feedwater alkalinity control is desirable. To eliminate carryover, boiler water alkalinity can be reduced by blowdown, which is at best an expensive method. However, the carbon dioxide liberated with the steam is almost purely a function of feedwater alkalinity and is not affected appreciably by blowdown. This emphasizes the desirability of controlling feedwater alkalinity, the de-

TABLE 1—ALLOWABLE TOTAL SOLIDS CONCENTRATION IN BOILER WATERS

Boiler Pressure	Max. Total Solids
0- 300 psig	3500 ppm
301- 450 psig	3000 ppm
451- 600 psig	2500 ppm
601- 750 psig	2000 ppm
751- 900 psig	1500 ppm
901-1000 psig	1250 ppm
1001-1500 psig	1000 ppm

gree of reduction being balanced between its cost and the cost of maintenance of traps and condensate lines subject to corrosion by the carbon dioxide redissolved in the condensate.

Reduction of total solids is important if only for the fact that the total solids figure is the classical basis for determination of blowdown schedule. Selection of the maximum total solids concentration that can be maintained without carryover must be tempered by consideration of the character of the solids. However, the American Boiler Manufacturers Association has set up standards which are generally acceptable and conservative; these are given in Table 1.

Silica is objectionable in boiler water due to its tendency at high concentrations to form hard scale on heating

TABLE 2—ALLOWABLE SILICA CONCENTRATION IN BOILER WATERS

Boiler Pressure	Max. Silica
150 psig	150 ppm
250 psig	100 ppm
400 psig	75 ppm
600 psig	50 ppm
900 psig	25 ppm
1200-2000 psig	5 ppm

surfaces and to be carried with steam into turbines where it deposits on blading. Both phenomena are most noticeable at high operating pressures. For that reason the maximum concentration allowable is a function of boiler pressure as is the case for total solids. Table 2, based

TABLE 3—COMPARATIVE CHEMICAL COSTS FOR REDUCTION OF HARDNESS

Chemical	Process	Formula	Cost, \$/Ton	Units per Unit CaCO <sub>3</sub> Hardness	Cost, Cents per Gr/Gal 1000 Gal	Comparative Cost
Lime (90%)	Precip.	Ca(OH) <sub>2</sub>	\$ 12	0.82-1.64	0.07-0.14	1.00-2.00*
Dol. Lime (65%)	Precip.	Ca(OH) <sub>2</sub> ·MgO	13	1.14-2.28	0.11-0.21	1.52-3.04*
Soda Ash	Precip.	Na <sub>2</sub> CO <sub>3</sub>	24	1.06	0.182	2.60
Salt	Ion Ex.	NaCl	12	3.15	0.27	3.85
Sulf. Acid	Ion Ex.	H <sub>2</sub> SO <sub>4</sub>	24	1.75	0.30	4.30
Caustic Soda	Precip.	NaOH	54	0.80	0.31	4.40
Phos. Acid (75%)	Precip.	H <sub>3</sub> PO <sub>4</sub>	110	0.88	0.69	9.8
Hydrochl. Acid (32%)	Ion Ex.	HCl	36	3.50	0.90	12.8
Disod. Phos. (Hyd.)	Precip.	Na <sub>2</sub> HPO <sub>4</sub> ·12H <sub>2</sub> O	60	2.39	1.02	14.6
Trisod. Phos.	Precip.	Na <sub>3</sub> PO <sub>4</sub> ·12H <sub>2</sub> O	60	2.53	1.08	15.5
Disod. Phos. (Anhyd.)	Precip.	Na <sub>2</sub> HPO <sub>4</sub>	150	1.11	1.19	16.9
Monosod. Phos.	Precip.	NaH <sub>2</sub> PO <sub>4</sub> ·H <sub>2</sub> O	180	0.92	1.19	16.9

\* NOTE: The requirements for lime will vary in the range indicated as the ratio of calcium to total hardness varies from 1.0 to 0.0, respectively. The same effect is shown by Tables 4 and 5.

upon actual operating experience, is offered as a guide for the control of silica concentration in boiler water. In certain cases where silica reduction in feedwater is not practical, blowdown must be scheduled on the basis of silica rather than total solids concentration. In such cases a review of the cost of silica reduction should be made to determine whether the investment for the process can be justified on the basis of savings in reduced blowdown.

#### Cost of Chemical Treatment

Having reviewed the principal factors governing the selection of feedwater conditioning equipment, the cost of obtaining satisfactory boiler water must be determined. Compromises usually must be made since the best boiler water is probably too expensive and generally unnecessary.

The comparative costs of hardness reduction are shown by Table 3. In this tabulation, the various reagents have been placed on an equivalent basis. Obviously, such a table cannot tell the complete story, since, for example, residual hardness will vary. Nevertheless, the reagents are in correct relative position. Incidentally, it is of interest to note that although salt costs about the same as lime on a weight basis, the relative cost of softening with sodium zeolite is two to four times that of softening with lime. This illustrates the failure of ion-exchange equipment to utilize completely regenerant chemicals, approximately only one pound of salt being exchanged by the

bed for every three pounds passed through it. The phosphates are shown to be expensive reagents and are used economically only on a relatively soft water or for supplementary treatment after initial hardness reduction.

Fig. 1 shows a typical two-stage hot-process system utilizing low cost lime and soda ash for primary treatment followed by phosphate treatment in a second sedimentation tank for removing residual hardness. For further economy of chemicals, concentrated boiler blowdown is recirculated back to the first-stage sedimentation tank. Stirring mechanisms in both tanks increase the efficiency of the precipitation.

Table 4 applies to the cost of alkalinity reduction. Again it is necessary to qualify these figures. Lime will reduce the bicarbonate alkalinity of most waters when this is associated with calcium and magnesium but can have no effect on sodium alkalinity. The only method of reducing sodium bicarbonate with corresponding reduction in total solids is by the ion-exchange process operated on the acid cycle. With the precipitation process or by direct addition, a byproduct is formed. However, the table forms a relative basis of comparison.

Fig. 2 shows the application of phosphoric acid to the hot-process softener for accomplishing alkalinity reduction in addition to hardness reduction. The raw water is of low hardness. Phosphoric acid is introduced ahead of the sedimentation tank and carbon dioxide and oxygen are removed by deaeration. Caustic soda is introduced for proper pH conditions to precipitate the hardness.

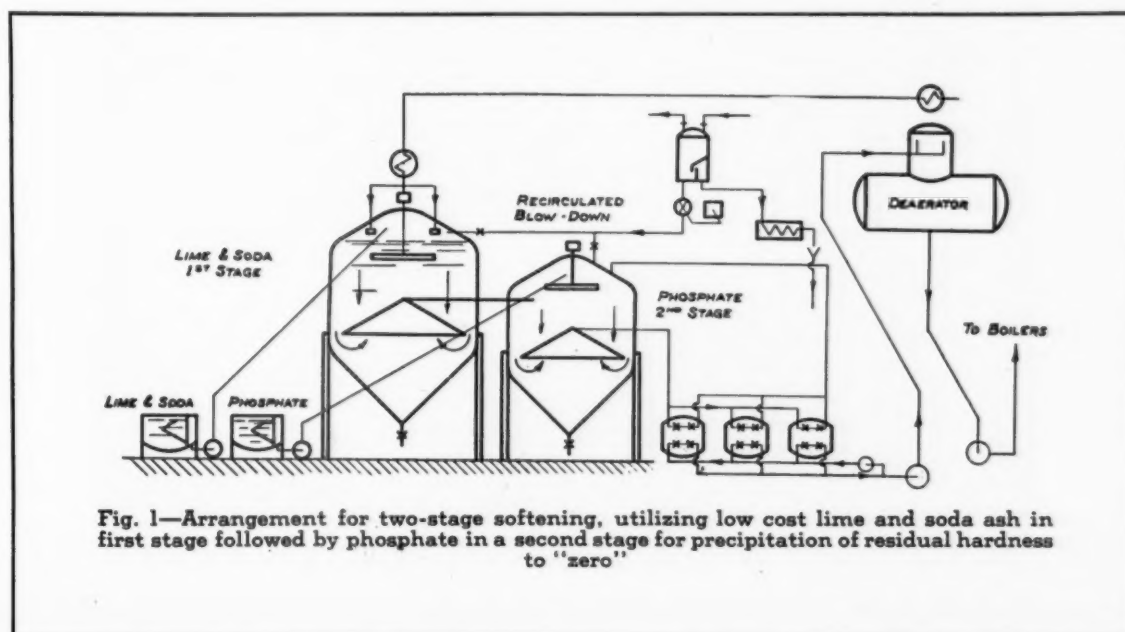
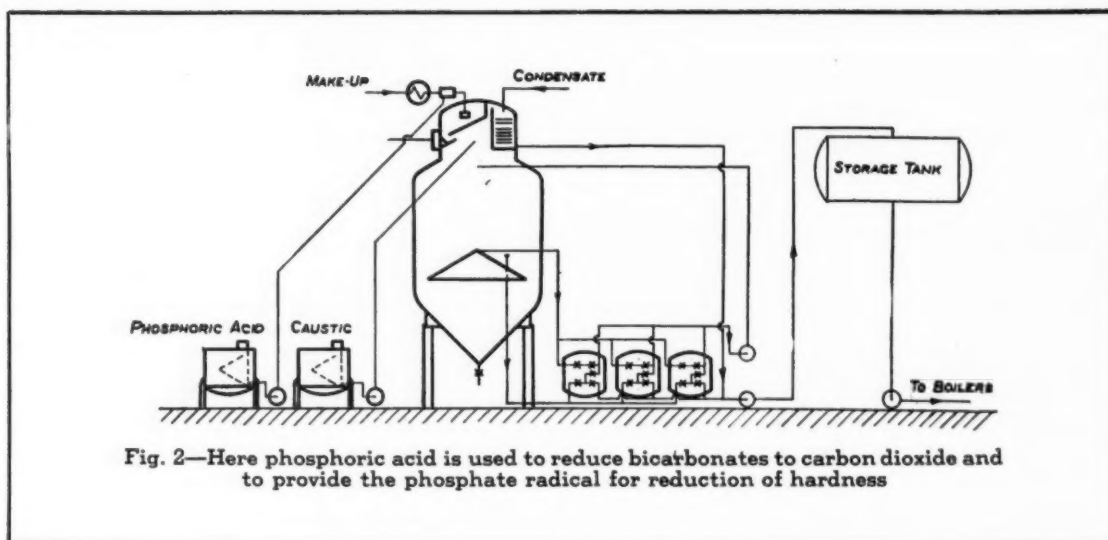


Fig. 1—Arrangement for two-stage softening, utilizing low cost lime and soda ash in first stage followed by phosphate in a second stage for precipitation of residual hardness to "zero"



Operating at 30 psi, this softener produces a water of controllable alkalinity with hardness of less than  $\frac{1}{2}$  ppm by gravimetric analysis.

Fig. 3 indicates a second method of alkalinity control: the blending of the effluents from both brine-regenerated and acid-regenerated carbonaceous zeolite units. Carbon dioxide is removed by mechanical means in a decarbonating tower and deaeration is provided separately for the boiler feedwater.

The cost comparison applying to reduction of total solids is given in Table 5. The reduction of total solids by these various reagents should be considered from the standpoint of the calcium and magnesium bicarbonates

in the raw water, since only the ion-exchange process operated on the acid cycle can effect reduction of sodium bicarbonate.

Chemical requirements for reduction of silica are difficult to estimate. In the precipitation process, silica is removed by adsorption so that the chemical dosage is a function of the inlet silica concentration and the desired residual concentration. The dosage is also affected by the presence of both inorganic salts—magnesium salts in particular—and organic constituents in the water. In the ion-exchange process a review of the literature indicates that with the fluoride process the sodium fluoride dosage must be approximately 175 per cent of theoretical.

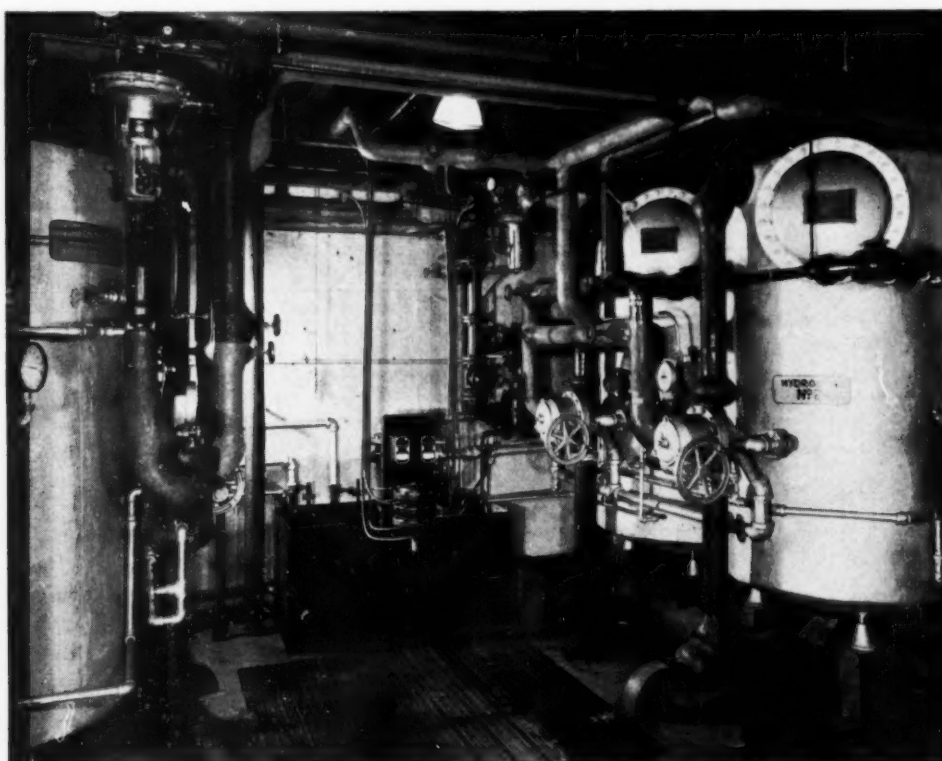


Fig. 3—Alkalinity of the blended effluent from double-unit sodium and double-unit hydrogen regenerated carbonaceous zeolite softeners can be accurately controlled

TABLE 4—CHEMICAL COST FOR ALKALINITY REDUCTION

Chemical	Process	Formula	Cost, \$/Ton	Units per Unit CaCO <sub>3</sub> Alkalinity	Cost, Cents per Gr/Gal 1000 Gal	Comparative Cost
Lime (90%)	Precip.	Ca(OH) <sub>2</sub>	\$ 12	0.82-1.64	0.07-0.14	1.00-2.00
Dol. Lime (65%)	Precip.	Ca(OH) <sub>2</sub> ·MgO	13	1.14-2.28	0.11-0.21	1.52-3.04
Sulf. Acid (66%)	Direct Add	H <sub>2</sub> SO <sub>4</sub>	24	0.98	0.168	2.40
Gypsum	Precip.	CaSO <sub>4</sub> ·2H <sub>2</sub> O	22	1.72	0.27	3.87
Sulf. Acid	Ion Ex.	H <sub>2</sub> SO <sub>4</sub>	24	1.75	0.30	4.30
Hydrochl. Acid (32%)	Direct Add	HCl	36	2.28	0.59	8.4
Phos. Acid (75%)	Precip.	H <sub>3</sub> PO <sub>4</sub>	110	0.88	0.69	9.8
Epsom Salts	Precip.	MgSO <sub>4</sub> ·7H <sub>2</sub> O	36	2.47	0.71*	10.2
Hydrochl. Acid (32%)	Ion Ex.	HCl	36	3.50	0.90	12.8

\* Including cost of lime for precipitation of magnesium.

Table 6 indicates the approximate chemical dosage for silica removal. An attempt has been made to anticipate the requirements of each reagent based upon reasonable silica reduction, the data having been taken principally from laboratory and field reports and a general review of the available literature.

Fig. 4 shows a 16,000-gph hot-process softener treating a low-hardness surface supply principally for silica removal. Magnesium sulphate is fed as an adsorbent

### Cost of Equipment

No attempt is made to present equipment costs which are necessarily variable. For example, with precipitation processes equipment cost is principally a function of load; with ion-exchange equipment it is a function both of load and concentration of salts in the incoming water. The picture is further complicated by the requirement for other auxiliary equipment, particularly deaerating ap-

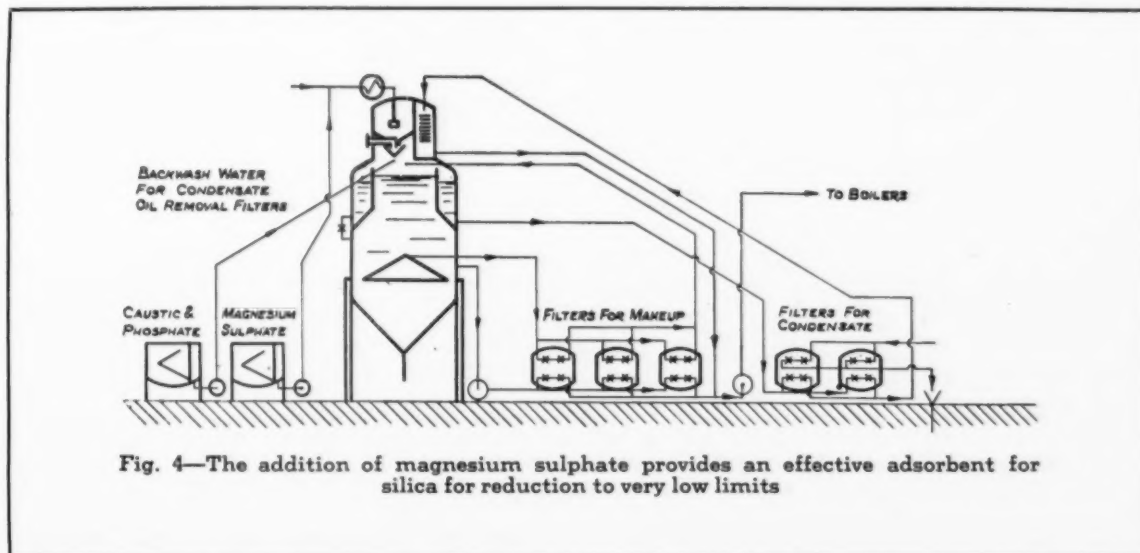


Fig. 4—The addition of magnesium sulphate provides an effective adsorbent for silica for reduction to very low limits

ahead of the softener followed by deaeration and proportioning of caustic and phosphate for hardness reduction. Condensate to the extent of 10,000 gph is deaerated separately in a tray deaerating compartment after passing through oil removal filters.

In considering these costs one must recognize that they are to be compensated for the blowdown schedule to be maintained. The blowdown schedule influences the quantity of water required and therefore the size of equipment. This also adds the expense of heat loss, which amounts to approximately five cents per million pounds for every 1 per cent blowdown if continuous blowdown equipment with a 20-deg terminal difference is installed.

paratus. Generally speaking, except for demineralizing equipment, the cost of the equipment seldom determines the selection since the fixed charges represent a small fraction of total operating cost when expressed as cost per thousand gallons of makeup. Nevertheless, it is obvious that equipment costs must be obtained, since occasionally it is found that investment for more expensive equipment with a lower cost of treatment may not be justified over less expensive equipment with a slightly higher cost of treatment.

### Factors of General Influence

There are three other factors governing the selection of equipment which can be covered only by generalities.

TABLE 5—CHEMICAL COST FOR TOTAL SOLIDS REDUCTION

Chemical	Process	Formula	Cost, \$/Ton	Units per Unit CaCO <sub>3</sub> Total Solids	Cost, Cents per Gr/Gal 1000 Gal	Comparative Cost
Lime (90%)	Precip.	Ca(OH) <sub>2</sub>	\$ 12	0.82-1.64	0.07-0.14	1.00-2.00
Dol. Lime	Precip.	Ca(OH) <sub>2</sub> ·MgO	13	1.14-2.28	0.11-0.21	1.52-3.04
Sulf. Acid	Ion Ex.	H <sub>2</sub> SO <sub>4</sub>	24	1.75	0.30	4.30
Soda Ash	Ion Ex.	Na <sub>2</sub> CO <sub>3</sub>	24	2.10	0.36	5.14*
Phos. Acid	Precip.	H <sub>3</sub> PO <sub>4</sub>	100	0.88	0.69	9.8
Hydrochl. Acid (32%)	Ion Ex.	HCl	36	3.50	0.90	12.8

\* NOTE: Reduction of solids by demineralization will be a summation of 3 and 4 and will amount to 0.30¢ to 0.66¢ per gr/gal per 1000 gal as the ratio of alkalinity to total anions varies from 1.0 to 0.0, respectively.

TABLE 6—CHEMICAL COST OF SILICA REDUCTION<sup>a</sup>

Chemical	Process	Formula	Cost, \$/Ton	Units per Unit SiO <sub>2</sub>	Cost, Cents per Gr/Gal 1000 Gal	Comparative Cost
Dol. Lime (35% MgO)	Precip. (Hot) <sup>b</sup>	Ca(OH) <sub>2</sub> ·MgO	\$ 13	9.6	0.89	1.00
Remosil	Precip. (Hot) <sup>b</sup>	Mg	160	3.36	3.84	4.32
Epsom Salts	Precip. (Hot) <sup>b</sup>	MgSO <sub>4</sub> ·7H <sub>2</sub> O	36	13.7	3.9-4.9 <sup>d</sup>	4.4-5.5
Ferrisul	Precip. (Cold) <sup>b</sup>	Fe <sub>2</sub> (SO <sub>4</sub> ) <sub>3</sub>	50	29.6	11.4-13.4 <sup>d</sup>	12.8-15.1
Fluorides	Ion Ex. <sup>c</sup>	NaF	200	7.5	16.6 <sup>e</sup>	18.6

NOTE:

<sup>a</sup> Based on initial silica of approx. 20 ppm.<sup>b</sup> Precipitation process based on reduction to 1 ppm SiO<sub>2</sub> in hot process, 3 ppm cold process.<sup>c</sup> Ion-exchange process based on reduction to 0.5 ppm SiO<sub>2</sub>.<sup>d</sup> Cost includes alkali for precipitation.<sup>e</sup> Cost includes additional acid and alkali required for regeneration because of the fluoride addition.

One of these is the presence of certain constituents in the water, such as color and turbidity. The presence of color in a water favors the selection of clarifying equipment and ion-exchange apparatus, this for the reason that color leached from vegetation inhibits precipitation of hardness in a sedimentation tank. The presence of turbidity, on the other hand, favors the selection of a precipitation type apparatus since the removal of turbidity and hardness may be accomplished in a single apparatus, ion-exchange softeners requiring that a turbid water be pretreated.

A second factor depends upon the individuality of the plant itself. One obvious item in this category is the limitation of space. Another, usually favoring ion-exchange equipment, is the requirement for large volumes of treated water for process or cooling, forcing the power engineer to accept treated process water and to doctor it for his boilers. Still another item in this category, usually favoring a sedimentation process by virtue of flexibility in selection of reagents, is variation in the characteristics of the supply, brought about by seasonal changes in surface water or raw water withdrawn from a number of wells on plant property.

The third factor is the cost of labor for installation, operation and maintenance. While current trends are toward completely automatic operation within the limits of practicality, routine tests and maintenance problems cannot be completely eliminated. The complexity of automatic controls requires higher caliber servicing to prevent avoidable outages.

The pressure of advertising new products, while serving a useful purpose, often draws attention from basic factors in equipment selection. Choosing water-conditioning equipment requires careful review of all reagents and processes: Reagents are selected with regard to their adaptability to reduce hardness, alkalinity, total solids and silica; whereas precipitation, direct addition, and ion-exchange classify the processes available.

A tabulation of reagents available for reduction of hardness, alkalinity, total solids, and silica on an equivalent basis offers a convenient index for process selection. Such an index shows lime or dolomitic lime to be the most economical reagent for a variety of applications. The low efficiency of ion-exchange equipment is illustrated by the relative positions of acid and salt in the cost index. Available silica removal data are sufficiently accurate to allow comparison of relative efficiencies of applicable reagents. Silica removal by ion-exchange is generally too expensive to be considered at present for treating makeup.

Equipment costs should be reviewed in conjunction with analysis of chemical treatment. Since fixed charges are a small part of operating cost, chemical cost is usually the important consideration. Other items influence

equipment selection by virtue of peculiarities in the existing plant, including the requirement for large volumes of process water, fluctuation of raw water characteristics and space limitations.



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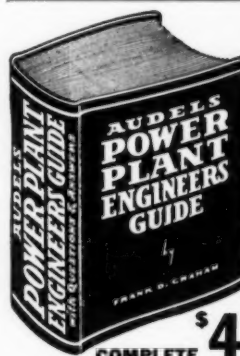
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# Appraisal of the Coal Industry\*

By J. E. TOBEY

Director, Fairmont Coal Bureau

The magnitude of the bituminous coal industry is indicated by the fact that 40,000 cars move two million tons daily from 7500 mines, having a total annual payroll of 1½ million dollars. At present 90 per cent of the coal is cut by machine and 59 per cent is loaded mechanically. Production per man-day is 6.1 tons. Research and mining trends are discussed.

WHAT is the Bituminous Coal Industry? Basically it consists of 7500 mines<sup>1</sup> in 23 states; 5466 operating companies; plant value around \$3,000,000,000; gross value of coal produced at the mines (1947) about \$2,570,000,000; annual mining capacity approximately 700,000,000 tons; annual production (1947) 619,000,000 tons; annual wage bill exceeds \$1,500,000,000;<sup>2</sup> annual purchase of supplies, equipment and repair parts exceeds \$500,000,000; number of miners, approximately 400,000; average production rate (1947) 6.1 tons per man-day (the highest rate in the world).

In this industry, 11 per cent of the mines produce 68 per cent of the coal and employ 65 per cent of the miners, while only one company produces more than 5 per cent of the entire annual output and only eleven companies produce as much as one per cent of the entire output. This is in contrast to other industries. For instance, in rubber, four companies produce 70 per cent of the total volume. Three companies in the automobile industry supply over 75 per cent of the automobiles, and there is a similar situation in aluminum, in steel and in chemicals. In coal, however, it would take the top four commercial companies combined to equal 10 per cent of the productive capacity.

To grasp the enormity of the bulk-volume business of the bituminous coal industry, just picture the 40,000 carloads (2,000,000 tons) of coal which must leave the mines each working day and travel over the nation's transportation arteries to markets in 48 states, some of which are more than a thousand miles distant. Then realize that 40,000 empty cars must also return to the mines each day. Failure of loaded cars to leave a mine promptly or the empties to return will cause a mine to close down. To

make the problem more complex, coal is produced from literally hundreds of seams, each of which varies from the others more or less with respect to physical and chemical characteristics, quality and multiple sizing. Different kinds and sizes of coal must be distributed for specific uses. Many coals must be washed and specially sized for certain use purposes.

To keep the system functioning smoothly requires almost perfect coordination of mining, sales and transportation facilities.

Of all the commodities produced in our country, coal is by far the largest in physical volume. The annual tonnage is approximately four times that of all our grain crops, including corn, wheat, rye, barley and other grains. It is 200 times the tonnage of our cotton crop. It is more than six times the tonnage of our iron ore production. At annual dollar value, it is more than the value of all the iron ore, gold, silver, nickel, zinc, lead and other non-ferrous metals produced in the U. S. It furnishes our railroads with more than 30 per cent of their total revenue freight and their prosperity is dependent upon a continuation of this traffic in large volume.

Furthermore, coal is a "great provider" in the chemical field and is related to more than 200,000 compounds, including plastics, drugs, medicines, explosives, fertilizers, dyestuffs, perfumes, etc.

The consumption of bituminous coal and lignite by consumer class in the United States in 1947 was as follows:

	Tons
Railroads, Class I.....	109,296,000
Coke.....	104,664,000
Electric power utilities.....	86,003,000
Steel and rolling mills.....	10,048,000
Other industrials.....	124,459,000
Retail dealer deliveries (domestic and some commercial).....	99,163,000
Cement mills.....	7,872,000
Colliery, bunker and foreign trade.....	4,178,000
Total of classes shown.....	545,683,000

In addition to the above U. S. domestic consumption, 42,760,702 tons was exported abroad and 25,848,000 tons shipped to Canada, making the total 614,291,702.

There is no known substitute for coke for metallurgical purposes, therefore, coal is indispensable for the production of iron and steel. Furthermore, the reserves of coal are so great and those of oil and natural gas so limited that coal is indispensable for other uses. As great as are the oil and natural gas industries, if the U. S. were en-

\* From a talk before the Rotary Club of Cincinnati, Ohio, June 3, 1948. The author has lately become president of Appalachian Coals, Inc.

<sup>1</sup> Producing over a thousand tons per year and 99.6 per cent of the national tonnage.

<sup>2</sup> Labor costs are approximately 60 per cent of the selling price of coal at the mine.

tirely dependent upon them for energy their proved reserves could supply the nation's requirements only for a period of 8½ years.

### *Synthetic Fuels*

Because of the stupendous demand for oil and the threatening shortage of domestic reserves, the Government is advocating that steps be taken to make this country self-sufficient and independent of Middle East oil through the construction and development of a synthetic fuels industry.

The Secretary of the Interior has recommended to Congress that plans be made extending from 5 to 10 years for sufficient capacity to manufacture 2,000,000 barrels of oil per day, which would represent about 36 per cent of present-day crude runs to stills. It is estimated that such a program would cost private industry, assisted by the Government, approximately \$9,000,000,000. In magnitude, this program would require 16,000,000 tons of steel and would be about ten times the size of the World War II synthetic rubber program. Coal and oil shale would be used as base materials and they would be required in tremendous quantities. Half the production would be from coal, requiring 500,000 tons per day, or nearly 200,000,000 tons annually.

Congress has already appropriated a total of \$60,000,000 for the use of the U. S. Bureau of Mines in developing demonstration and pilot plants for synthetic fuels from coal, lignite and oil shale. The bureau has so far built throughout the country three demonstration and three pilot plants, using the Fischer-Tropsch and Bergius processes. Also, a project on underground (coal) gasification is being conducted by the Alabama Power Company and the U. S. Bureau of Mines for the production of synthetic gas. If successful, this process offers the potentiality of exploiting coal seams too thin or uneconomic to mine and also worked-out mine areas in which some coal remains.

The largest commercial coal company (Pittsburgh-Consolidation) and the largest oil company (Esso-Standard Oil) are jointly building a pilot plant to develop a commercial process for gasifying Pennsylvania coal. Their process seeks a hydrogen-rich gas usable for heating, especially for winter time, and for synthetic gasoline and fuel oil. Other great American oil companies are doing similar research on coal, having in mind the enormous reserves of sub-bituminous, lignite and oil shale in the Western states.

### *Utilization*

In the utilization field the electric utilities are an excellent example of the strides being made by coal. In 1947 these utilities used a total, including anthracite, of 89,543,867 tons, compared with 41,827,358 tons in 1929 (a high record year); and the Edison Electric Institute has just recently estimated that consumption will reach 153,500,000 tons by the year 1961.

All other industries with the exception of the railroads, are expected to use coal on an increasing scale. Diesel locomotives are making inroads on coal-burning locomotives but the increased use by other industries should more than make up for loss of tonnage in this field. Further, this trend away from coal by the railroads may be checked by a shortage of high-grade (No. 3) diesel fuel oil

or the substitution of synthetic oil from coal, or new types of more efficient coal-burning steam or gas-turbine locomotives. Most certainly, from a national security standpoint, it would be folly to have our entire rail transportation system dependent upon diesel fuel from natural petroleum sources.

In the residential field, coal may suffer some further losses to competitive fuels, but in the end it should triumph here because of the exhaustion of these scarcer fuels, aided and abetted by improved coal-burning equipment, synthetic fuels from coal and the heat pump, a device which will both heat and cool homes using principally coal generated electricity.

### *Research and Development*

Bituminous coal is one of the very few industries in the U. S. engaged in cooperative research as distinguished separately from research done by individual companies and government agencies.

It founded its initial program in 1933, during the very depths of the depression. The industry not only suffered the losses normal to all industries at the time, but it was being dealt hard blows by the new fuels, oil and natural gas. It was down but not out, and its fighting spirit emerged in several forms. It was then that Appalachian Coals, Inc., with the sanction of the U. S. Supreme Court, was organized as the first and greatest regional sales agency in any industry, to merchandise and service the southern high-volatile coals on a scientific and more profitable basis. Many other agencies patterned after it sprang up within the industry.

The National Coal Association and A.C.I. stimulated the formation of Bituminous Coal Research, Inc., and with the support of progressive coal-operating companies and several coal-carrying railroads a research program was commenced. Starting out on a very modest scale, its activities have been continually stepped up through the years. This year it is operating on a budget of approximately one million dollars, embracing 50 projects covering the development of practically all classes of fuel-burning equipment, including stoves, ranges, circulating heaters, water heaters, furnaces, boilers, stokers, pulverizers, steam and gas-turbine locomotives, plus some fundamental research in synthetic fuels. Work is being done at the present time in the laboratories of the following eight institutions: Battelle Memorial Institute, Carnegie Institute of Technology, Massachusetts Institute of Technology, Johns-Hopkins University, West Virginia University, Illinois Institute of Gas Technology, Purdue University and the University of Illinois. In addition to this, considerable development work is being done in the field. Today B.C.R. has the support of 363 companies representing coal, railroads and equipment manufacturers.

Public relations and promotional work for the coal industry are handled by Bituminous Coal Institute.

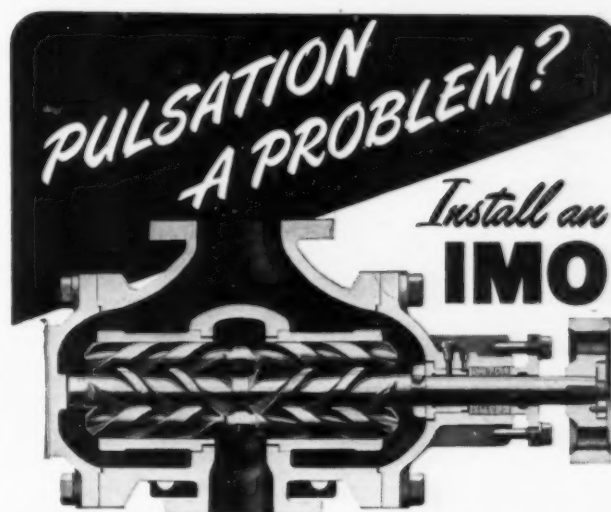
### *Trends in Coal Mining*

The trend is definitely toward more and more mechanization and less manual labor, fewer mines but increased daily capacity per mine, higher production rate per man-day, fewer but larger operating companies, and increased use of electricity.

A comparison two years after both World War I and World War II reflects this trend.

	1920	1947
Number of bituminous mines.....	8,921	7,500
Number of operating companies (producing over 1000 tons per yr).....	7,600	5,466
Average number of men working daily.....	639,500	405,000
Total production bituminous coal and lignite.....	568,666,700	619,000,000
Total payroll.....	\$1,138,000,000	1,307,000,000
Degree of Mechanization:		
Per cent cut by machine.....	60	90
Per cent loaded mechanically underground.....	0	59
Production per man-day, tons...	4.0	6.1

Twenty-five years ago it cost \$1.50 to \$2.00 per ton of annual capacity to open a large deep mine. This covered the development work and complete physical plant below and above ground. Today the cost ranges normally from \$5.00 to \$7.00, or approximately three times as much; however, in some instances it has reached \$10.00. This means to develop a new mine of 1,000,000 ton annual capacity would cost between \$5,000,000 and \$10,000,000. This large increase in capital cost is due to higher material and labor costs, more and heavier mechanical equipment, heavier rails or belt conveyors, preparation plants including washers, better structures and safety devices. Hence, the industry which is financed mainly by venture capital in the form of common stocks, will require vastly more capital than at present.



With an IMO Pump delivery is not interrupted by the periodic strokes of a piston or the opening and closing of valves and ports. The turning of the rotors in an IMO forces the fluid from suction to discharge in a continuous, uniform flow.

IMO pumps can be furnished for practically any capacity and pressure required for oil, hydraulic-control fluids and other liquids.

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## Note these Big Savings Made by R & I Moldit Chrome Refractory Cement

Eighteen tons of R & I Moldit Chrome Refractory Cement were shot by a cement gun into the floor of a slagging bottom boiler in only 3½ hours, or 35 man-hours.

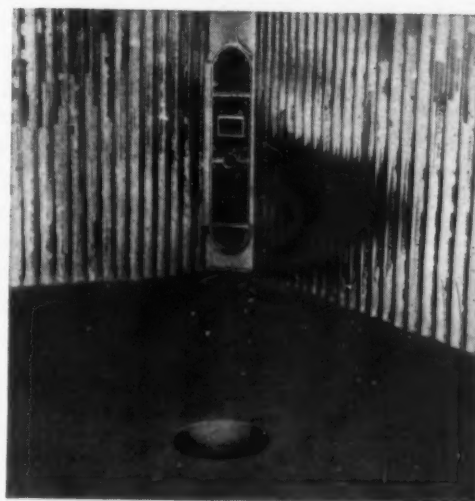
It previously took 661 man-hours to pound and hammer eighteen tons of plastic chrome in the same floor. Boiler outage was thus greatly reduced by using Moldit Chrome.

A bridge wall 28-ft. wide by 14-ft. high by 18 inches thick was burning out in a stoker, over fired by oil, every three weeks. Brick and super-duty bricks of all kinds were tried without success. Finally, keys were made in the wall and R & I Moldit Chrome shot 2 inches thick over the face. This increased the life of the wall six times.



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Slagging bottom boiler, showing tap hole in floor where slag runs out. Moldit Chrome was shot over tubes in floor.

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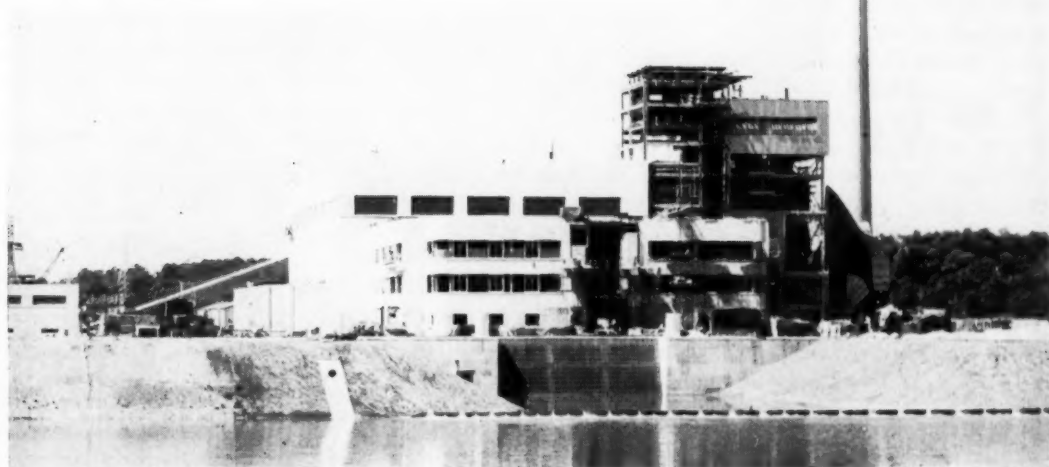
Philadelphia 3, Pa.

# The "New Power St

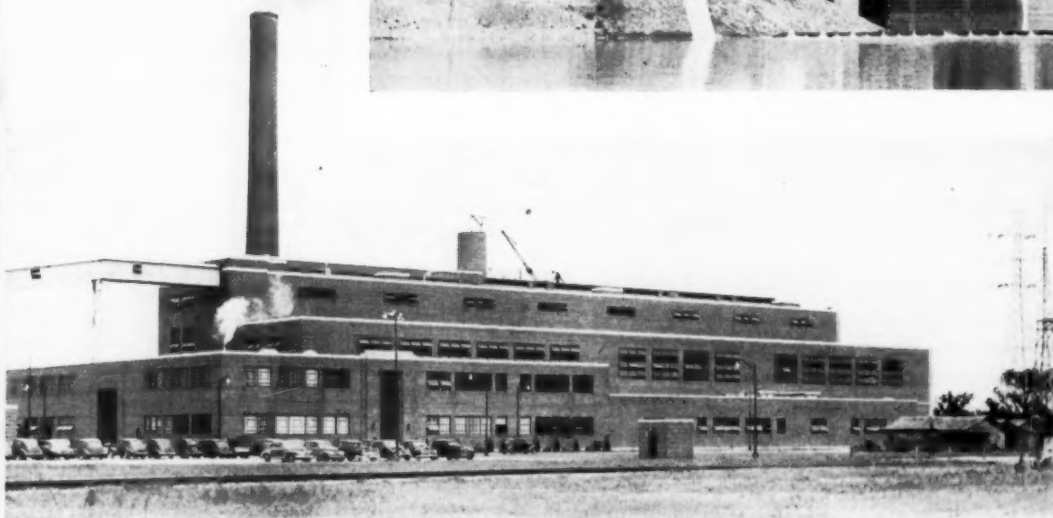
Some Post-war Stations in the Eastern



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2



3

4

1. Meredosia Station of Central Illinois Public Service Co.
2. O. H. Hutchings Station of Dayton Power & Light Co.
3. Havana Station of Illinois Power Co.
4. Port Jefferson Station of Long Island Lighting Co.
5. Hickling Station of New York State Elec. & Gas Co.
6. Jennison Station of New York State Elec. & Gas Co.
7. Lakeside Station of Rochester Gas & Elec. Corp.
8. Possum Pt. Station of Virginia Elec. & Power Co.

COMBUSTION—August 1948



# ew Look'' in er Stations

in the Eastern and North Central States



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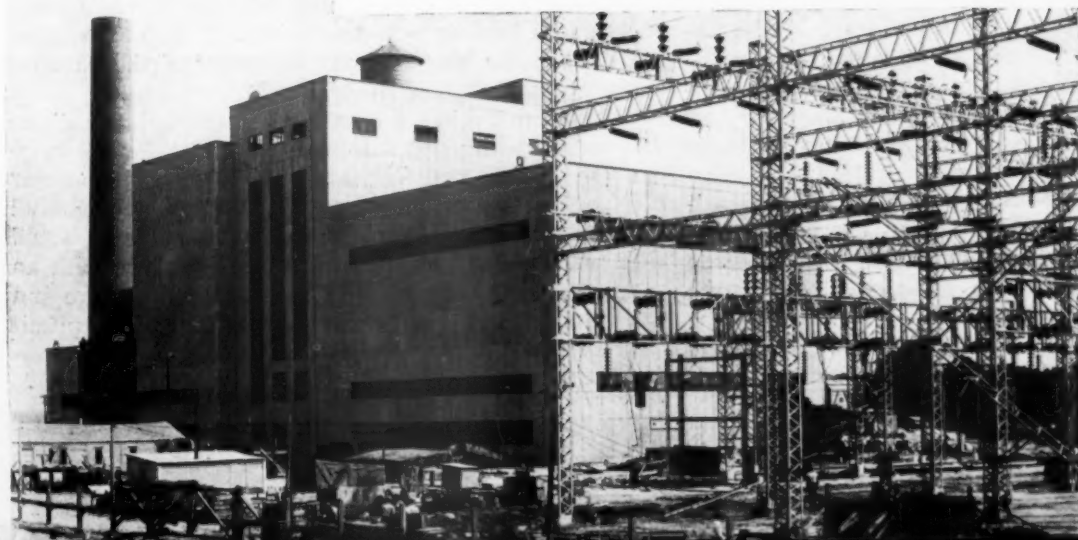
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Photos by  
H. R. TOWSE



8



# New Steam Cycle Proposed

By J. F. FIELD

Controller, S. E. Scotland Div.,  
British Electricity Authority

Commenting on a paper entitled "The Gas Turbine for Public Electricity Supply," by H. G. Bell and D. M. Smith before the Incorporated Municipal Electrical Association at Eastbourne, England, on June 8, 1948, Mr. Field proposed a new cycle embodying certain features from both the gas turbine and the steam turbine. In the belief that many COMBUSTION readers would find this intriguing he has sent us a copy of this discussion, together with his answers to some questions that have been raised.—Editor.

THE open-cycle gas turbine, particularly in the compound form with regenerator, reheat, etc., is only less exacting in the matter of fuel than the gasoline engine and the diesel; hence, fuel cost dominates to such a degree that a case for this type can only be made for land power purposes in Britain by taking the savings in capital cost, as compared with a steam plant, and using these savings, as long as they would last, to subsidize the more expensive fuel. This consideration has restricted it to an exceedingly poor load factor from the public electricity supply point of view as compared with steam power produced from coal. It would be, of course, a different story if the plant were required to work in conjunction with hydroelectric power. While the closed cycle machine need not necessarily suffer from the expensive fuel limitation, the capital cost per kilowatt would probably equal or exceed that for steam.

It has recently been suggested by certain makers of gas turbines that both open- and closed-cycle machines could be adapted to the generation of steam from the exhaust gases, but any attempt to generate steam in this manner would, in effect, result in a bulky low-pressure boiler, because the inlet gas temperature would be much lower than in normal boiler practice.

## *Borrowing from the Gas Turbine*

However, steam cannot afford to rest on its laurels, and can benefit from recent gas-turbine progress. To demonstrate what is meant by this observation the author would draw attention to Fig. 1, which represents an ordinary open-cycle gas-turbine compressor set. Fig. 2 shows the same thermodynamic arrangement but without direct contact between the combustion gases and the compressed air which is mostly the working fluid of the open-cycle gas turbine. Provided the pressure drop in the heating element is sufficiently low one would, with the same temperature and pressure ratio, get almost exactly the same thermal efficiency from the one arrangement as from the other. The ideal diagram for 1200-F operation is shown in Fig. 3. This indicates the two main thermo-

dynamic weaknesses of the nonregenerative open-cycle gas turbine for land purposes, inasmuch as it necessarily has a greatly extended range of heat intake temperature and a very high exhaust gas temperature, with corresponding low cycle efficiency.

Fig. 4 indicates a machine reminiscent of Fig. 2, inasmuch as the working fluid is arranged to be indirectly heated, but with a fundamental difference in that the exhaust pipe from the turbine is turned into what was previously the air inlet to the compressor and a quantity of feedwater is entrained in the gas by means of an atomizer. The machine would be started like any other of its kind by motoring the generator. The atomizer feedwater spray would then be turned on, the mist passing with the air in the system through the compressor. The mixture would be compressed adiabatically and heated with consequent saturation of the air, while simultaneously heat is released in the combustor and raises the saturated air to a temperature suitable for admission to the turbine. After expansion through the turbine with the production of useful work a portion of the gas equal to the quantity of feedwater injected is bled off through the pipe at the bottom, and before many seconds of running, the internal portion of the machine would be operating in an atmosphere of steam only.

Fig. 6 represents the process in thermodynamic form. Starting at point *D*, corresponding to the inlet to the turbine, a quantity of steam is expanded adiabatically to *E* and produces power. The bulk of the steam then passes into the lower pipe where feedwater is injected through an atomizer, and causes cooling at constant pressure along line *E* to *F* and slight wetting of the steam from *F* to *B*, still at the same pressure. Thereafter the slightly wet mixture of steam is compressed adiabatically from *B* to *C*, then fed to the heating element by means of which its temperature is raised to the point *D* for readmission to the turbine. The theoretical ratio of atomized water to steam recirculating is indicated by the ratio of *BN* to *AB*, and a corresponding weight of steam is bled off to process. The machine as a whole has subjected the atomized water spray to a heat-drop process indicated theoretically by *BCDEFB*, the heat rejected by means of the pass-out steam being indicated by *LBFEM*.

The area of rejected heat can be regarded as a direct means of raising steam to condition *E*, the cold water having sensible heat *GH*, latent heat *HK* and superheat *KE*. Such a machine operated with a suitable initial temperature, ratio of expansion and back pressure would necessarily have almost identical performance with an open-cycle gas turbine using the same temperature and pressure ratio. For a medium size machine of this primitive type one might expect, down to atmospheric pressure, a thermal efficiency of the order of 17 to 18 per cent,

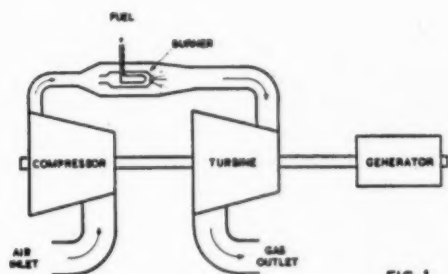


FIG. 1

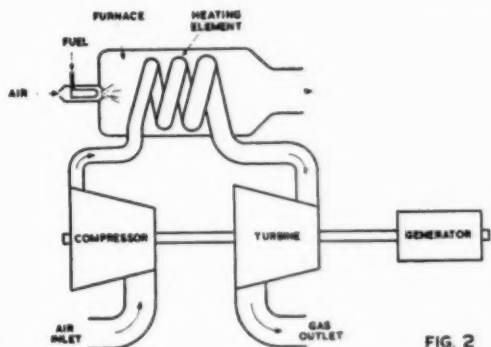


FIG. 2

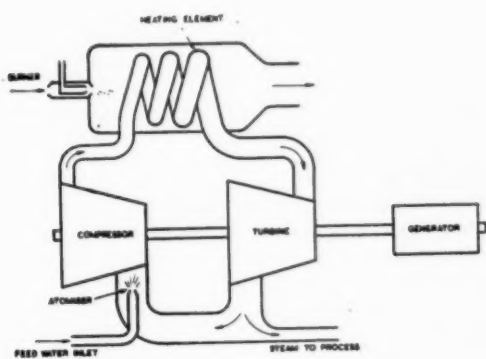


FIG. 4.

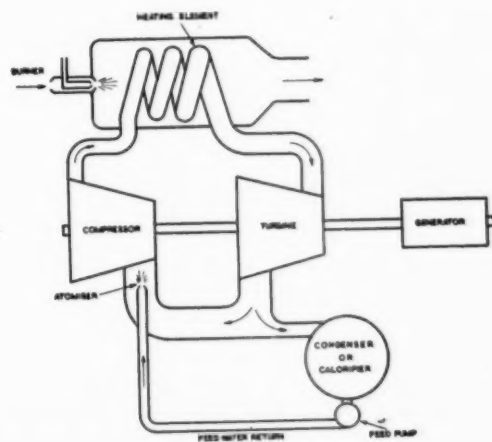


FIG. 5.

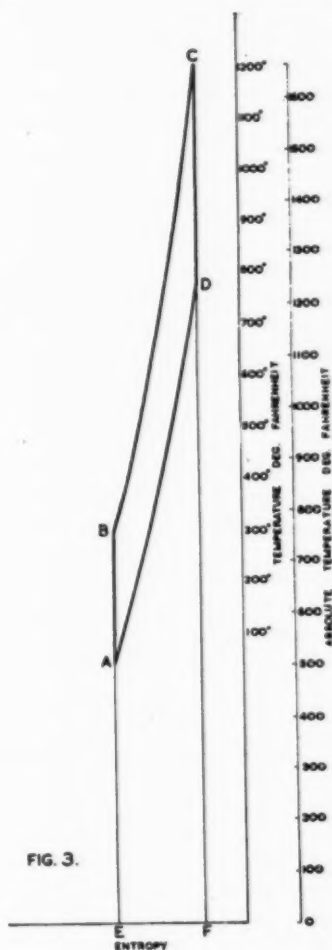


FIG. 3.

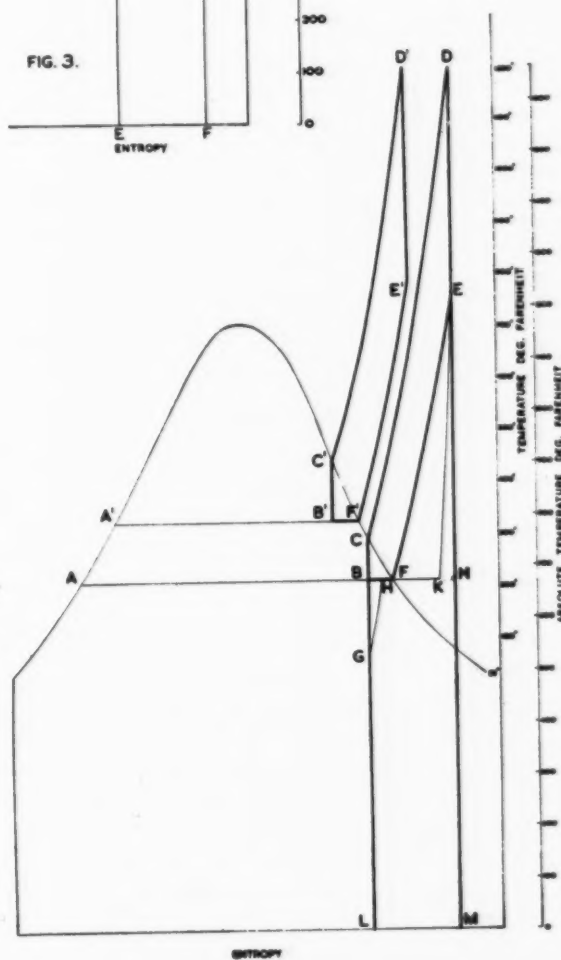


FIG. 6

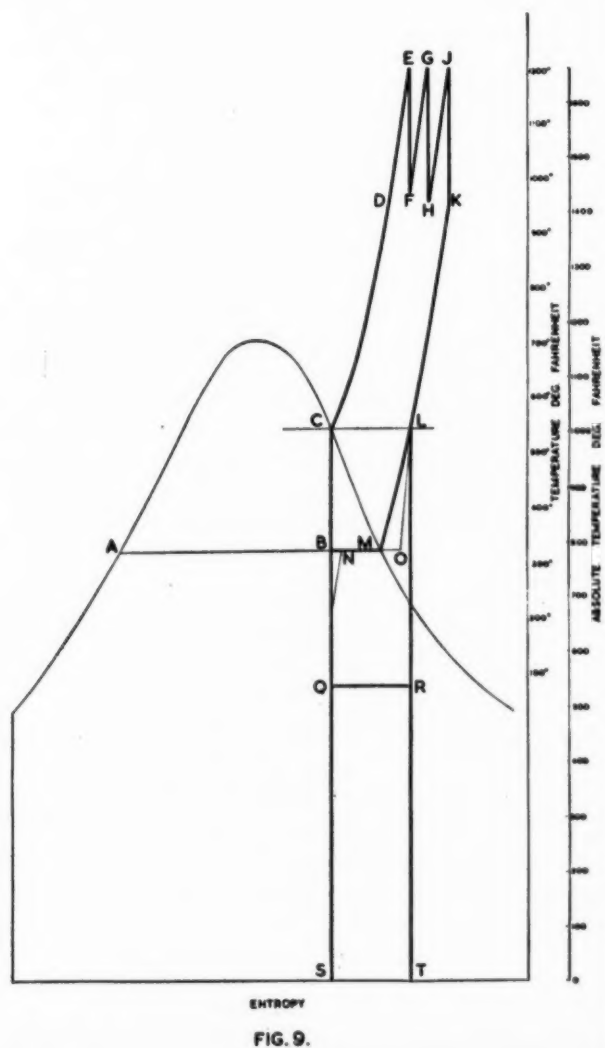
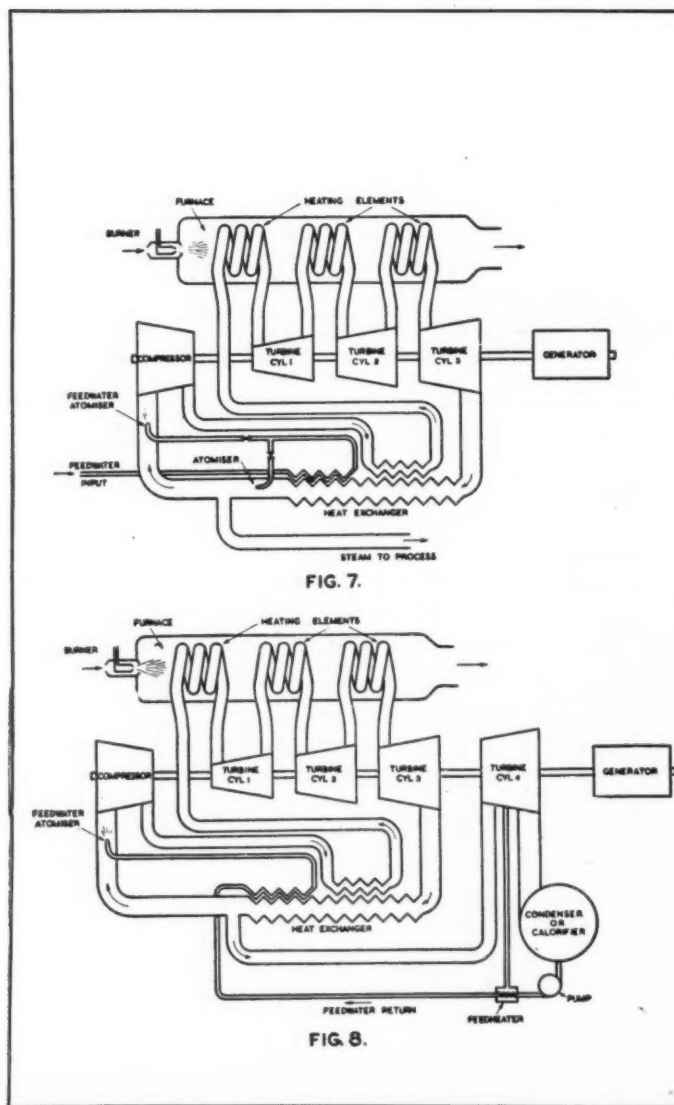
the remainder of the heat passing out as process steam. If one were committed to the use of a closed cycle to utilize pulverized coal as fuel, then this would be a great advantage. By increasing the back pressure one could cause the performance diagram to raise the saturation line so that  $A' B' C' D' E' F'$  would indicate the process with a smaller heat drop but with higher pressure process steam available. Incidentally the deterioration in the ratio of mechanical energy to process heat would be much less than for a similar backing up of pressure on a Rankine cycle back-pressure steam set.

Another advantage is that such a machine is not so limited in its efficiency when reduced in size. Further it would be a simple matter to arrange for almost precisely the same thermodynamic process by adding a condenser to the process pipe and return the condensed water through a pump to the atomizer, thus making a closed power system of extreme simplicity, consisting of a superheating element, a turbine, a condenser, a water atomizer and a compressor. No high-pressure feed pump and no boiler would be necessary.

Such a machine is, of course, amenable to the improvements in thermal efficiency which have been attempted with considerable success in open- and closed-cycle gas turbines, and it has special advantages of its own at the

lower temperature end of the cycle. In fact, it has inherently all the advantages of the closed air cycle arrangement with one overwhelming advantage in that the rejection of heat at the lower end could take place by means of a condensable vapor at constant pressure with a condenser of comparatively small surface and with very low temperature drop as compared with air and without interstage cooling of the compressor.

Fig. 7 indicates a functional diagram of such an improved machine. The corresponding theoretical temperature-entropy diagram, Fig. 9, indicates steam being admitted to the first heater element at  $D$ ; heat added to point  $E$ ; the steam expanded through the first turbine cylinder as indicated by  $EF$ ; then being reheated in the second superheater element corresponding to  $FG$ ; expanding through the second turbine element corresponding to  $GH$ ; reheated through the third superheater element corresponding to  $HJ$ ; and expanded through the third turbine element corresponding to  $JK$ . The steam would then pass through a steam heat-exchanger or regenerator at substantially constant pressure as indicated by  $KL$ , with water being injected by atomizers before and after the take-off point for process. Differential manipulation of the valves controlling the atomizers would enable the operator to obtain steam at the lower



operating pressure in any selected condition of superheat or wetness, as indicated by the line *LMB*. The rejected heat is indicated by *SBNLT*. A small portion of the steam circulating in the system could also be bled off at the highest pressure and temperature part of the cycle, but necessarily at the expense of mechanical power output.

It is interesting to note that Fig. 9 shows a theoretical heat drop for the upper part of the cycle approaching 50 per cent of the total heat fed to the cycle, since this diagram was prepared on a very accurate temperature-entropy chart with a higher operating pressure of 1000 psi and a lower pressure of 100 psi. It would appear that such a machine could be built, for the pressure and temperature conditions stated, in relatively small sizes to have a thermal efficiency for mechanical (electrical) output of the order of 30 per cent or better, and with exhaust steam available for process at no less than 100 psi pressure, with easy control of steam conditions. By operating to a lower range of pressure it is obvious that the "mechanical" thermal efficiency would go up. Perhaps the best way of arranging for this is indicated by Fig. 8, where a further cylinder for adiabatic expansion of steam has been added with a condenser, pump and feed heater as shown in the more primitive form in Fig. 5.

With the latter arrangement one could, of course, generate power only, exhausting the steam to the usual 1 in. Hg or thereabouts. In that case the theoretical heat drop would be extremely advantageous as compared with any kind of Rankine cycle at present in use, even if one allowed for the fact that an upper steam temperature of 1200 F was being considered. Thermal efficiencies of well over 40 per cent should be possible.

### Comments

The following questions and comments have been raised by E. Hallowell in a communication addressed to the *Electrical Review*, of London:

1. As combustion air will leave the superheaters at about 1500 F how does Mr. Field propose to recover this waste heat, and if by means of a combustion air preheater of special construction, what losses will be incurred in the process?
2. In view of the relatively high compressor admission temperature and absence of intercooling, is not the negative to gross work ratio entirely prohibitive with commercially attainable turbine and compressor efficiency ratios?
3. In ordinary steam turbines reheating is hardly considered worth while with pressure ratios of 300 to 1, yet two-stage reheating is here advocated with a ratio of 10 to 1. In view of inevitable pressure drops, will such reheating have any appreciable effect in improving thermal efficiency?
4. How does Mr. Field propose to deal with compressor blade erosion and other troubles with very wet steam, especially near the compressor outlet?

Preliminary calculations made with reasonable wetness fractions and with commercial efficiency ratios of 89 per cent and 84 per cent for turbine and compressor, respectively, show overall thermal efficiency values well below ordinary steam-turbine practice.

Mr. Field would also appear to have made the mistake of assuming that working temperatures equal to those used with internal-combustion gas turbines will be practicable, when actually for equal creep values internal combustion has an advantage of from 200 to 800 deg F, depending on the adiabatic heat drop in the first turbine stage. This is due to the fact that there is no transmission of primary heat through pressure-stressed tubes as is the case with external-combustion gas or steam turbines.

The entropy diagrams of Mr. Field have little real significance and a Sankey diagram based on commercially attainable efficiency ratios for turbine and compressor would be illuminating.

### Reply by Author

Commenting on question (1), it is unlikely that combustion air would leave the superheaters at as high a temperature as 1500 F. With proper contraflow arrangement of the heating surfaces the actual temperature should not exceed 1200-1300 F, but higher temperatures would not matter since regenerative air heating would be applied exactly as in high-pressure water-tube boiler technique. There is no difficulty about this. Ljungstrom type air preheaters have been applied in the United States in certain industries up to 1500 F and, with suitable heat-storage material, could go higher. Mr. Hallowell should also note that the Escher Wyss closed air cycle machine uses a tubular air preheater working at similar temperatures. The "boiler" efficiency figures could certainly equal and conceivably exceed those obtained with today's best water-tube boiler practice, through suitable research and development.

With reference to item (2), either a single or multi-stage centrifugal compressor or a multi-stage aerofoil type could be used. The admission temperature is that of the wet steam entering the compressor inlet, and since the latter type of compressor is in effect an inverted steam turbine the low temperature of operation would make it exceedingly easy to build. The compressor could be made entirely of mild steel. The compressor outlet temperature would be that of saturated steam at the higher operating pressure so that the outlet temperature need never exceed about 600 F. One of the outstanding advantages would be the avoidance of intercooling which is a fundamental necessity for high efficiency when a noncondensible fluid such as air is used. The ideal negative process for a gas turbine would be the lowest possible temperature isothermal followed by an adiabatic, but one cannot do this with a noncondensable gas. Intercooling cuts down the negative work and simultaneously raises the cycle efficiency in a gas turbine, but the injection of atomized water into an atmosphere of steam gives almost perfect isothermal compression with further saving in negative work. The machine has similar characteristics, including a similar order of negative work to a gas turbine working to a similar temperature and pressure ratio, but in practice there is no question that the negative work would be less than in a comparable gas turbine, because of the constant pressure character of the water injection process. For the upper "gas turbine" part of the cycle the negative work might be a rather higher proportion of the gross work than in a gas turbine working with cold air, in spite of avoiding the need for intercoolers as already mentioned, but when the positive work of the lower part of the cycle with virtually no negative work (only a feed pump) is added the negative work for the machine as a whole should be substantially less than for a comparable gas turbine. That is why the thermal efficiency should be higher.

With reference to item (3), one could ask precisely the same question with reference to gas turbines. These were all originally developed for one stage of heating without a regenerator between the turbine exhaust and the air to the heater, and the difficulty was to get enough margin of output to be useful. This problem was solved by going to what were then fairly high upper temperatures and thereafter very great improvements were made to gas turbines by adding one reheating stage plus a regenerator. I would cite, for example, the Beznau No. 1 machine recently installed in Switzerland by Brown Boveri. This has an all over pressure ratio of about 9 to 1. A somewhat similar machine is under construction for the Trafford Park Power Station by Metropolitan-Vickers. Both these machines have very great improvement in thermal efficiency over a simple open cycle using the same initial temperature and that which applies to gas must necessarily apply to steam in the superheated condition.

The problem of pressure drop has apparently been quite successfully tackled in the only closed-cycle gas turbine so far tried out, and there is no question that suitable design of the heaters required for a steam cycle would result in a low enough pressure drop for the purpose. Tests on the original Escher Wyss machine indicated extremely low pressure drops through both regenerator and heater elements, and the same could apply to superheated steam.

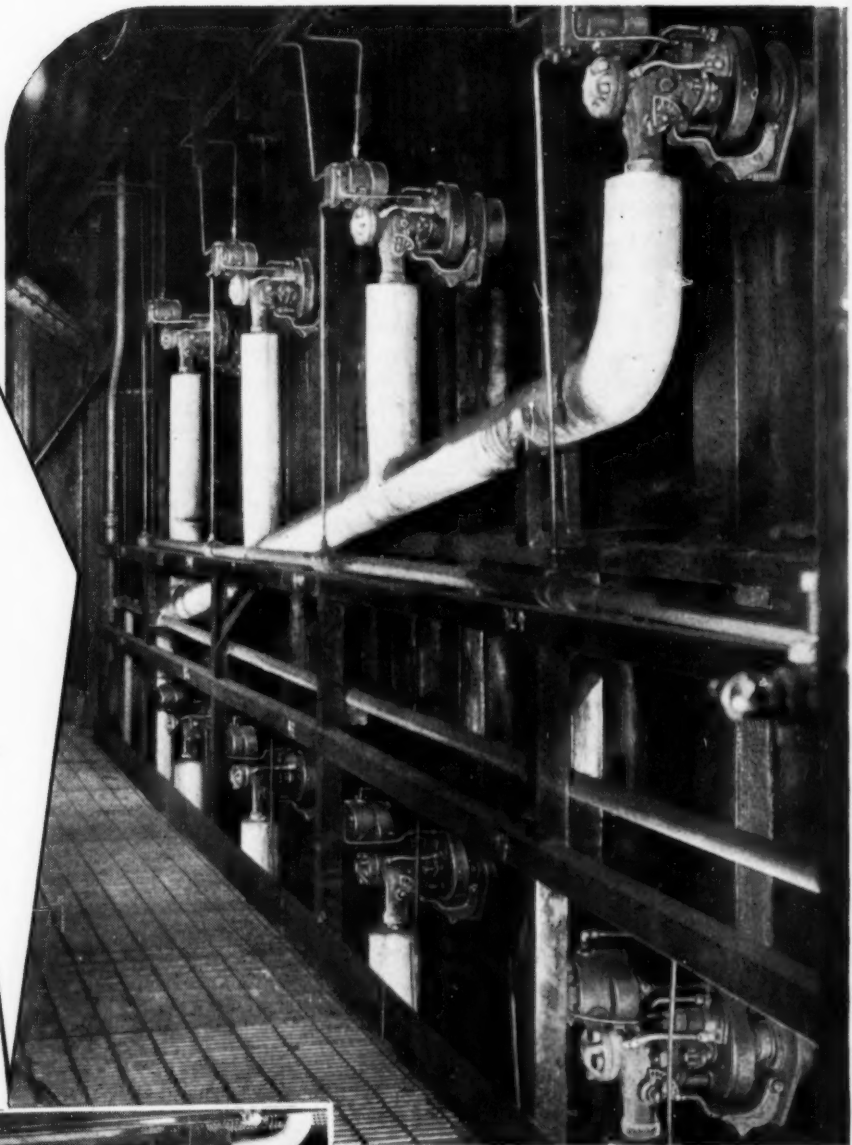
With reference to point (4), it should be remembered that water is injected into the returning flow of superheated steam in a fine atomized condition and the infinitesimal particles of water suspended in the steam are whipped through the compressor and converted also to steam in a time interval estimated at microseconds, so that these small atomized particles of water cannot possibly coalesce into bigger drops, the impact of which is a known cause of low-pressure blade erosion in a steam turbine.

It is quite impossible for this to happen in the kind of compressor

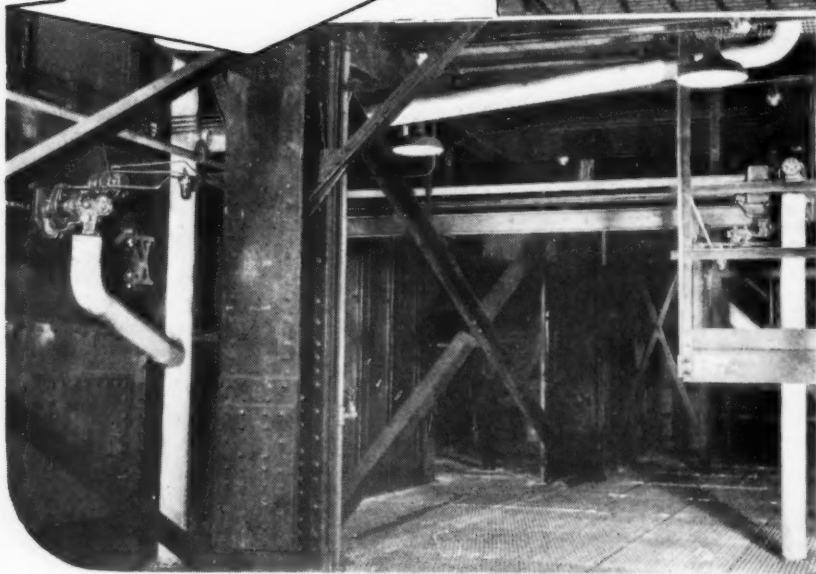
(Continued on page 45)

# VULCAN soot blowers

ON THE JOB  
at  
Williamsport  
Station



Eight Model E-3 Vulcomatic Rotary Units provide efficient cleaning of the Economizer section.



A Model E-3 Vulcomatic Rotary Unit at the rear of the Superheater tubes is shown at the left; one of the T-2 long retractable Vulcan Units, used on the furnace slag screen tubes, appears at the right

Modern "Know how" in soot blower efficiency is well demonstrated by this new Vulcan installation that cleans the Potomac Edison Company's new 350,000 lb. steam generator, installed in the Williamsport Power Station and built by Combustion Engineering. Steam at 900 psi is reduced to 180 psi through special orifices in the heads of the units. The soot blowers are air-motor-driven and controlled by pneumatic push buttons from a central instrument panel.

## VULCAN SOOT BLOWER CORPORATION

DU BOIS, PENNSYLVANIA

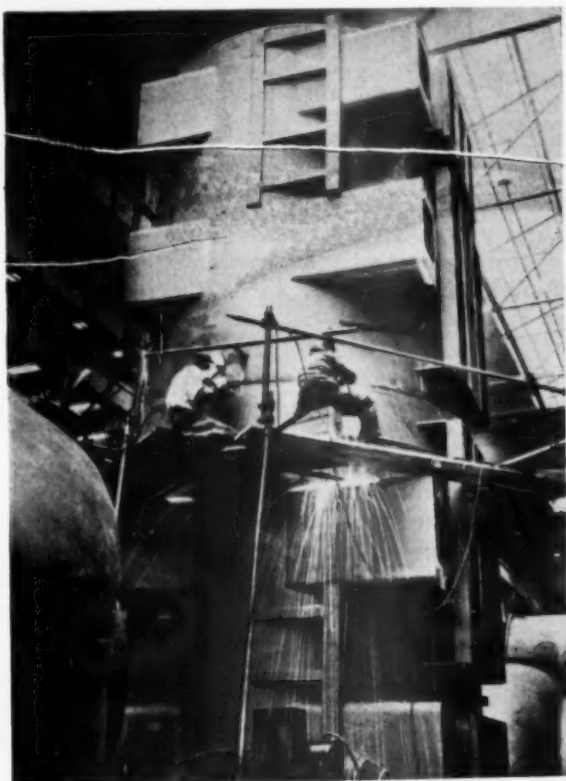
(Continued from page 43)

arrangement described. Even the first stage of compression in a multi-stage compressor of this type would reduce the wetness fraction substantially. The character of the losses which occur in aerofoils of this type is well known, and it is not beyond the bounds of possibility that a saturated vapor compression process applied in this way would benefit relative to a dry gas compression process in the manner in which these losses are absorbed in the working fluid. Obviously the best way to investigate this point is by actual experiment.

Mr. Hallowell's preliminary calculations, if made with a turbine admission temperature of say 950 F and with the efficiency figures he mentions would probably result in poorer performance than with ordinary steam-turbine practice, and indeed, attempts to get a useful output out of gas turbines at these temperatures in the early days showed very poor efficiencies compared with steam, but it has already been shown for several years to be a different story above 1100 F for gas turbines, and if superheated steam were used instead there is evidence that the relative advantage over the Rankine cycle would also improve as the temperature increased.

With reference to Mr. Hallowell's last paragraph, the temperature-entropy diagrams were included to make the text clear to those who have specialized in the study of thermodynamics. They were not put in to deceive the average engineer as to the probable deficiencies of the process. Any serious student of this subject would be well aware that in actual practice such diagrams differ considerably from theoretical perfection, and that theoretical perfection is merely a tool in the process of thinking about thermodynamic problems.

Generally with reference to Mr. Hallowell's last two paragraphs, I would refer him to what has been achieved already by the closed cycle air turbine of the Escher Wyss type. Either Escher Wyss are wrong in their claims or Mr. Hallowell is wrong in his argument, for all I am doing at the top end of the cycle is to substitute superheated steam for air in a closed cycle. At the bottom end of the cycle my scheme has, of course, very great thermodynamic advantages over an air or gas cycle due to the constant pressure character of the condensable vapor process, and the fact that rejected heat is in the form of steam which can be controlled for conditions over a wide range of pressure and superheat or wetness.



Welders in General Electric Schenectady turbine shop shown joining two 15-ft sections of a stator frame of a 150,000-kw turbine-generator, one of the largest ever built by the company

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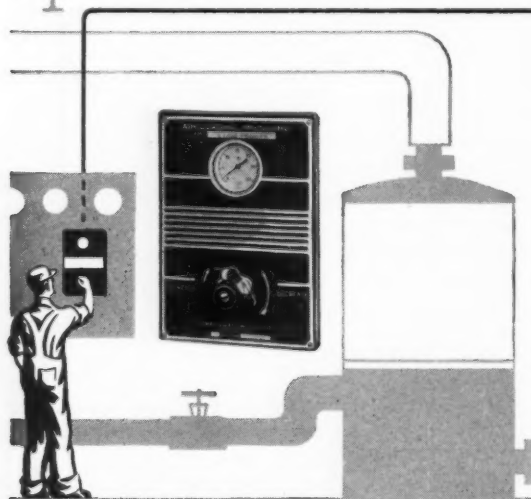
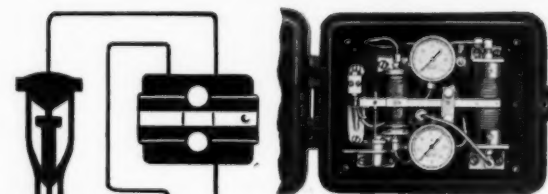
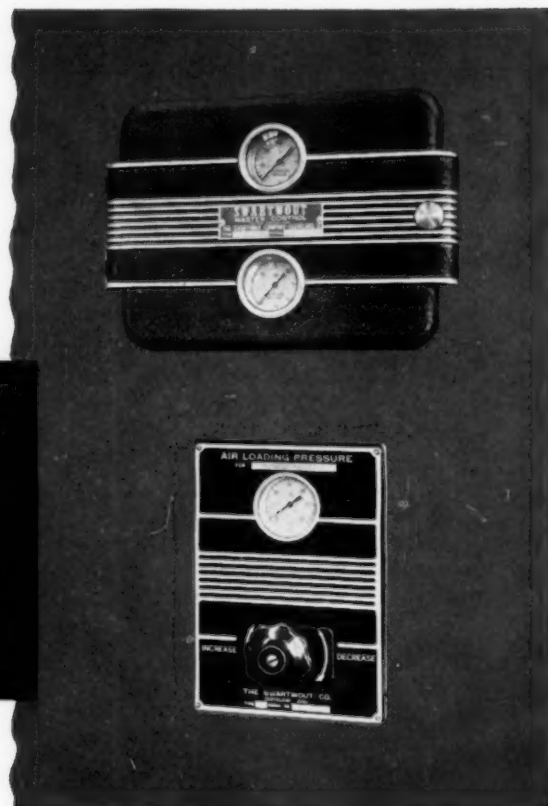


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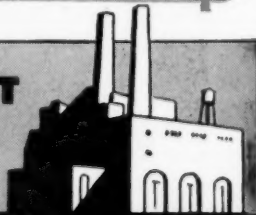


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# Internal Treatment with Magnesium Chloride in Absence of Phosphate

By F. H. LONG and W. A. POLLOCK

Wisconsin Electric Power Company

This paper which was presented at the A.S.M.E. Semi-Annual Meeting, May 30-June 4, 1948, represents a progress report on experience with the 1340-psi high-makeup unit in the Commerce Street Station of the Wisconsin Electric Power Company, where use of magnesium chloride has practically eliminated carryover of sulfate into the superheater and silica deposits on turbine blading.

THE Commerce Street Station in Milwaukee has a three-drum bent-tube boiler, having a rated maximum steam output of 375,000 lb per hr at 1400 psi, 900 F. The present operating pressure is 1340 psi, and normal steam flow is the full load of 375,000 lb per hr.

The tandem-compound 1200-psi turbine is rated at 35,000 kw with full condensing load, and 24,000 kw when the maximum steam bled-off to the heating system is 240,000 lb per hr. There are four stages of extraction for feedwater heating, with maximum pressures corresponding to 6, 57, 182 and 345 psig. The latter three points are also used for bleeding steam for commercial heating.

Makeup water to replace the steam sent out to the Milwaukee central heating system comes from Lake Michigan through the city mains. It is heated slightly by the hydrogen-cooler of the turbine-generator and then softened by hydrogen zeolite. At pH 3.5 the softened water is vacuum-degasified with a 10 to 15 deg F. rise in temperature. Finally, the free mineral acidity is neutralized with NaOH by automatic pH control.

## *Turbine-Blade Experience Previously Reported*

As reported in a paper at the 1946 Midwest Power Conference, turbine stage-pressures began to rise rapidly as soon as high makeup loads were carried. The rate of increase was quite erratic, and followed no apparent definite cycle, although it averaged about 3 per cent per day.

Use of conductivity as a measure of total carryover was not successful, due to non-condensable gases, the corrections

for which could not be evaluated with sufficient accuracy.

Many silica determinations were made on the boiler water, steam and turbine hotwell condensate. These data indicated a proportional relationship between silica in the boiler water and steam, and between the silica in the steam and silica deposition on the turbine blading. Boiler water silica values between 2 and 19 ppm gave silica values in the steam between 0.02 and 0.17 ppm, respectively, and corresponding silica deposition values of zero to 0.12 ppm. Attempts to correct the carryover trouble by feeding various chemicals were ineffective.

Steam-water washing the turbine was necessary about once a month to remove soluble deposits. Caustic washing to remove insoluble deposits was only partly successful.

Internal use of magnesium oxide in the absence of phosphate was finally resorted to for silica removal. It was effective in preventing deposits below No. 2 bleed point (57 psi), but not above.

Excessive deposits of sodium sulfate in the superheater prompted the internal use of barium chloride for removal of about one-half of the sulfate, but did not conclusively show a benefit.

Subsequently it was discovered that carbonaceous zeolite from the softeners was gaining access to the feedwater. Correction of this fault by a high rinse rate following each regeneration to remove fines which had been deposited in piping, inactive during regeneration, and by limiting maximum flows to 83 per cent of design, practically eliminated deposits, as shown by the then only one-fifth per cent per day rise in stage pressures.

The continued employment of MgO was then stopped, and in the absence of phosphate this transferred trouble from the turbine to the boiler. The MgO did not remain in suspension, which would have permitted it to be blown out, nor did it entirely form a harmless sludge. Rather, it formed a paper-thin scale consisting of serpentine (magnesium silicate) in the front sections of the boiler, a porous fragile soft scale in the middle section, and partly sludge in the rearmost section. During boiler shutdowns, the scale would chip off, with the consequent tendency for lodging in screen-tube pockets with danger of stopping circulation. It was therefore necessary to clean out thoroughly

all of this loose scale at each outage. As a further precaution, the furnace wall and screen tubes were turbed at each outage, and the entire boiler annually.

Elimination of phosphate allowed the possibility of calcium scale, so it became necessary to adapt the softener process for extremely low calcium in the makeup. By changing to a high-capacity resin in January 1947, it has been possible to operate continuously with an average of less than one-tenth ppm  $\text{CaCO}_3$ , and maximum of one-quarter ppm.

Fortunately, modern condenser design has held condenser leakage to a negligible quantity.

## *Experience Subsequent to April 1946*

The continued use of MgO for silica reduction, and avoidance of ingress of carbonaceous zeolite, precluded the necessity for further turbine washing. Although frequent boiler outages have been necessary as a safeguard against a possible screen tube failure due to accumulation of chip scale, this frequency has gradually been reduced as experience accumulates.

To help reduce the amount of chip scale, a change from the "shot" method of treatment to "continuous" feed was made in September 1946. Shortly thereafter, to help further, the rate of MgO treatment was reduced from 7 ppm to about 4 ppm (in makeup).

The resulting expected increase in boiler water silica (from the former 2 ppm to 5 ppm) was a sacrifice in turbine cleanliness, but was accepted because of the scheduled turbine inspection for re-blading and consequent ash blasting during the summer of 1947.

In spite of the increase in silica, there was no noticeable increase in No. 2 stage pressure.

## *Use of Organic Treatment*

For further possible help in prevention of the serpentine chip scale, the use of organic treatment was started in December 1945. This treatment consisted of 6 ppm (makeup basis) of dry sodium lignin sulfonate. It was mixed with the MgO and fed continuously. No evident effect on turbine deposits could be observed. Although there was an apparent increase in superheater deposits, the coincident rise in makeup demand with cold weather precluded any direct com-

TABLE 1—DEPOSITS ON TURBINE BLADES AT INSPECTION OF JULY 1947\*  
HIGH-PRESSURE SPINDLE

Stage	Temp., F	X-ray Analysis	Description of Deposit
Back of dummy	900	Sodium sulfate 111, unidentified	Stages 1 to 14: Trace, soft, dark gray
1	900	Sodium sulfate 111, unidentified	
12	755	Sodium sulfate 111, unidentified	
16	685	Unidentified	
17	677	Unidentified	Stages 15 to 22: Gradual increase to 3/4 in. soft; gradual change from gray to light buff color. Quite uniform, entire convex side†
18	660	Unidentified	
19	642	Unidentified	
20	620	Unidentified sodium chloride	
21	600	Sodium chloride, unidentified	Stages 23 to 25: About 1/32 in. on 50% of convex side, soft
22	577	Sodium chloride, unidentified	
23	555	Sodium chloride, unidentified	
24	530	Sodium chloride, unidentified	
25	500	Sodium chloride, unidentified	Stages 26, 27: Trace
26	470	Sodium chloride, unidentified	
29	355	Alpha quartz, sodium chloride	Stages 28, 29; about 1/100 in. soft
			Stage 30: Trace

\* X-ray analysis by courtesy of L. A. Burkardt, Allis-Chalmers Co., Milwaukee, Wis.

† Negligible on concave side for entire spindle.

Chemical analysis of "unidentified" indicates  $\text{Na}_2\text{SO}_4 \cdot 3\text{NaHCO}_3 \cdot 4\text{NaCl}$ .

parison of the effect of the organic treatment on carryover. This treatment was used for a total of 390 million pounds makeup over a four-month period (about 3 runs).

The improved boiler cleanliness, resulting from the combination of changes, made it possible to lengthen runs to 160 million pounds of makeup, which covered one month at maximum loads with 60 per cent makeup.

The still incomplete elimination of chip scale, however, seemed to indicate the need for more organic treatment. But the resulting possibility of more carryover, prompted a change to another brand of similar type treatment, containing an antifoam additive. This brand was used at the rate of 9 ppm (on makeup basis). Although during the use of this latter treatment, the mild weather necessitated only moderate makeup loads, there was a slight increase in stage pressures which indicated carryover. This increase may have been due to the fact that during the latter part of this run, the "shot" method of adding the MgO again had to be resorted to because of the lack of proper equipment for proportioning the suspension of MgO over the widely varying loads in the mild weather season. The length of run in which this latter brand of organic treatment was used, amounted to 168 million pounds of makeup over a period of three months, at the end of which the turbine was inspected. A summary of the inspection is given in Table 1 and Table 2.

#### Next Run in Absence of Organic Treatment

In the next run, after turbine inspection, the organic treatment was omitted because the turbine had been fairly dirty, and the prevention of chip scale in the boiler was rather far from 100 per cent. The rate of MgO treatment, shot-fed, remained about the same as previously (4 ppm).

The run was concluded with 162 million pounds of makeup over a four-month period. No noticeable increase in stage pressures had occurred. The superheater, however, had nearly twice as much sodium sulfate as the previous run before the turbine inspection. Apparently the "shot" method of feeding caused the increase in deposits. Since the total amount of steam generated was 870 million pounds,

this sodium sulfate gave a calculated value of 0.15 ppm deposited from the steam. The average boiler water analysis during this run was as follows, in ppm: phenolphthalein alkalinity (as NaOH) 23, organic (as phenol) 3.2 for first quarter of run, 0.26 for the last three-quarters, sodium sulfate 247, sodium chloride 55, sodium sulfite 8, silica 3.2, suspended solids 2. Chip scale formation in the boiler also increased very considerably, due to shot-feeding and absence of organic treatment.

#### Use of Magnesium Chloride and Organic

The increase in chip scale during the previous run emphasized the desirability of a continuous feed of magnesium hydroxide, and the need for more effective dispersion.

A trial of magnesium chloride was therefore prompted. It was fed in solution at the rate of 23 ppm  $\text{MgCl}_2 \cdot \text{H}_2\text{O}$  (equivalent to about 4.6 ppm MgO, makeup basis). Sufficient caustic soda for complete conversion to  $\text{Mg}(\text{OH})_2$  was fed independently. Organic treatment (the original brand without antifoam) was dissolved in the same solution as the  $\text{MgCl}_2$  in the proportion equivalent to 6 ppm. Both solutions of magnesium chloride and caustic soda entered the system at the suction of the turbine hotwell pump.

On this run 154 million pounds of makeup was used over a period of one month, during the first third of which MgO was used as before, and magnesium chloride

during the latter two-thirds, since there was some delay in obtaining the magnesium chloride.

No increase in turbine stage pressures was evident. The superheater wash water had less sodium sulfate than ever before, amounting to only 5 1/2 lb, which for 270 million pounds of steam generated gives a calculated value of 0.02 ppm deposited. The average boiler-water analysis during this run was, in ppm: Phenolphthalein alkalinity (as NaOH) 27, organic (as phenol) 2.13, sodium sulfate 165, sodium chloride 120, sodium sulfite 0.7, silica 3.3, suspended solids 16. Furthermore, the chip scale was much less.

The one deleterious effect, however, was the formation of deposits in the feed-water stage heaters, as evidenced by the rapid increase in terminal temperature difference, this being the worst in the last stage, which rose at the rate of 1 1/2 deg F per day. Prevention was effected during the latter part of the run by reducing the continuous feed of caustic to give a pH of 9.5 and "shot" feeding the remainder, past the heaters.

#### Second Run with $\text{MgCl}_2$

Due to the rapid fouling of the stage heaters, it was necessary to acid-clean them after the first run in which magnesium chloride was used.

The second run was then started with conditions the same as at the end of the first run, namely the partial treatment of caustic by continuous feed and remainder by shot feed to have pH 9.5 in the feed-water. This method, however, did not prove completely effective in preventing heater deposits and it was necessary to resort to splitting the  $\text{MgCl}_2$  feed similarly to the caustic, but not in the same proportion. About 75 percent of the  $\text{MgCl}_2$  was by continuous feed, and 25 percent by "shot." This second run with  $\text{MgCl}_2$  used 257 million pounds of makeup over a period of 48 days.

The amount of chip scale in the boiler increased considerably, in somewhat greater proportion than would be expected from the amount of makeup, probably due to the amount of shot feeding.

No apparent increase in turbine pressures occurred. The superheater wash water again showed only seven pounds of sodium sulfate, or 0.02 ppm deposited

TABLE 2—DEPOSITS ON TURBINE BLADES AT INSPECTION OF JULY 1947\*  
LOW-PRESSURE SPINDLE

Stage	Temp., F	X-ray Analysis	Description of Deposit
1	280	Amorphous silica, magnetite	Stage 1: About 1/100 in. grayish tan color on convex side; 1/10 in. along up-stream edge. Slight film of nearly black deposit on concave side.
2	260	Amorphous silica, barium sulfate magnetite	
3	240	Amorphous silica, barium sulfate magnetite	
4	315	Amorphous silica, barium sulfate magnetite	
5	195	Barium sulfate, magnetite	Stages 3, 4: Thickness gradually decreases. Outer portion quite soft, especially along upstream edge, but quite hard underneath
6	175	Barium sulfate, magnetite	
7	155	Amorphous, magnetite	Stages 5 to 10: Negligible. "Unidentified" is largely organic
8	135	Amorphous, magnetite	
9	115	Unidentified, magnetite	
10	92	Unidentified, magnetite	

\* X-ray analysis by courtesy of L. A. Burkardt, Allis-Chalmers Co., Milwaukee, Wis.

Low-pressure cylinder: Deposit pattern similar to spindle, but about 50 per cent greater and somewhat softer.

Last three stages had a black, glossy, brittle deposit, greatest on last stage. "Ice-circled" along down-stream edge. Not very tenacious. Mostly organic with a brownish red ash of iron oxides.

## Electric Output and Fuel Consumption Still Increasing

Figures on electric output and fuel consumption by electric utilities for June and for the first six months of the current year have just been released by the Federal Power Commission.

During June the production of electricity was 22,705,337,000 kwhr, which represented the highest June production on record and exceeded that of the same month last year by 12.2 per cent. Of this, fuel-burning plants produced 69.4 per cent.

For the first six months of 1948 the output was 137,240,593,000 kwhr which was 10.7 per cent greater than the first half of 1947.

Additions to installed capacity in electric utilities during June amounted to over 128,000 kw, bringing the total installed to slightly under 54,000,000 kw.

Industrial power production in June, including generation by railway power plants, amounted to 4,456,033,000 kw, which was an increase of 5.5 per cent over that for the same month last year. The combined utility and industrial power output for the twelve months ending June 30, 1948, exceeded that of the corresponding period a year earlier by 10.1 per cent.

Electric utility power plants consumed 7,828,602 tons of coal during June 1948 which was 18 per cent more than that of June 1947. Gas used amounted to 43,388,840 mcf which represented an increase of 31.2 per cent, and fuel oil showed a decrease of 4.3 per cent compared with that of May.

## Spreader Stoker Research

Sponsored by Bituminous Coal Research, Inc., a committee under the chairmanship of W. S. Major and made up of representatives of eight spreader stoker manufacturers and others from the bituminous coal industry, has been formed to study possibilities of extending the versatility and overall efficiency of this method of firing which has now become so widespread.

Plans have been formulated for conducting tests on representative spreader stokers by the fuel engineering staff of Battelle Memorial Institute.

## Lends Gas Turbine for Locomotive Development

Under a cooperative agreement between the Bureau of Mines and the Locomotive Development Committee of Bituminous Coal Research, a large gas turbine which had been destined for Russia under the Lend-Lease Program will be made available to the latter group for experimentation on the use of pulverized coal as a fuel for gas-turbine locomotives.

This 40,000-cfm unit and one of 23,000 cfm were obtained by the Bureau of Mines from the War Assets Administration after being declared "surplus" by the State Department. The larger unit will be used in tests to be conducted at the Committee's laboratory in Dunkirk, N. Y. Following these tests the turbine will be returned and the data obtained will be made available

to the Bureau for use in its allied research on the production of synthetic liquid fuels from coal. Information gained from these tests will be used in completing the design of the two experimental coal-burning gas-turbine locomotives now being constructed for the Locomotive Development Committee.

The smaller unit will be employed in the Bureau's second underground coal gasification experiments at Gorgas, Ala.

## To Study Drying of Lignite

Because lignite is a high-moisture coal that tends to crumble upon exposure to air, it presents a difficult transportation problem and its present use is restricted primarily to areas adjacent to the lignite fields. Therefore, to help expand the geographic distribution of a fuel which represents nearly a fifth of the nation's coal reserves, the Government, through the Bureau of Mines, is starting work on a lignite research laboratory at Grand Forks, N. D., which will concentrate on improved methods of drying.

In addition to development of effective drying methods to permit the transportation of lignite to more distant areas, and thus ease the demand for higher rank fuels, the research will also be directed toward more efficient lignite gasification methods.

**Correction:** Figs. 1 and 3 of Mr. Dawson's article on boiler feed pumps in the July issue should be transposed.

## The Cover Photograph

The photograph on the cover of this issue shows the recently completed power plant of the Reykjavik Municipal Electric Works, in Reykjavik, Iceland. It contains a 90,000 lb per hr C. E. two-drum steam generator fired by pulverized coal and supplying steam to the turbine at 500 psi, 800 F.

## Personals

H. L. Watson has retired as president of De Laval Steam Turbine Company and is succeeded by George W. Smith, Jr. Mr. Watson's association with the company covers 35 years, the last six years as president and from 1935 to 1942 as executive vice-president. Mr. Smith joined De Laval in 1947 as assistant to the president.

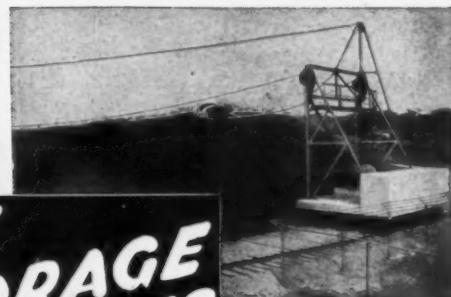
Thomas C. Buchanan has been given an interim appointment by President Truman as a member of the Federal Power Commission. A former member of the Pennsylvania Public Utility Commission, Mr. Buchanan fills the vacancy created by the retirement of Commissioner Richard Sachse.

Julian E. Tobey for several years past Director of the Fairmont Coal Bureau with headquarters in New York, has resigned to rejoin Appalachian Coals Inc., as its president. He will be succeeded by Earl C. Payne as acting director. Mr. Payne has long been associated with the Pittsburgh-Consolidation Coal Company, as consulting engineer.

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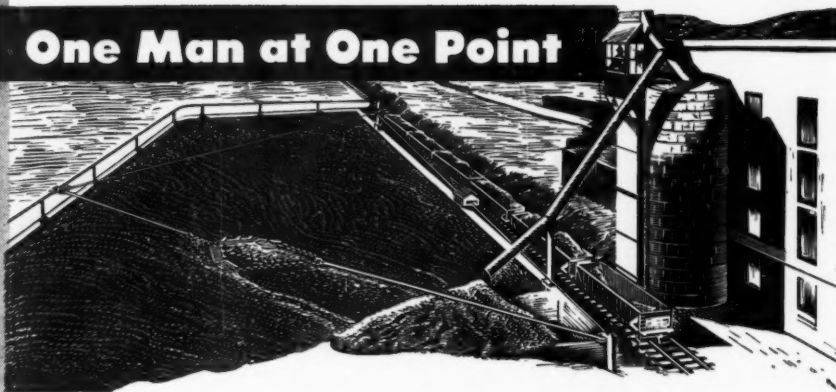
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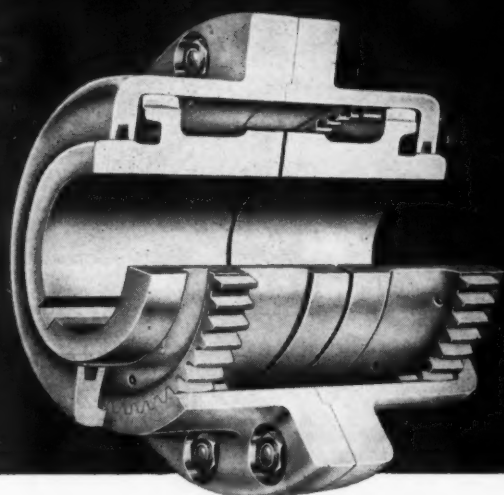
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Fig. 21

Fig. 22

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Fig. 4-F



Fig. 13

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